This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

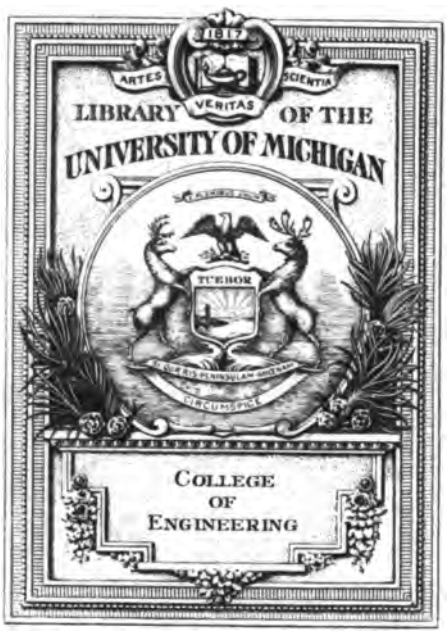
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


1817
ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
COLLEGE
OF
ENGINEERING

TRANSACTIONS

OF THE

73656

INSTITUTION OF NAVAL ARCHITECTS.

VOLUME XXXIX

INTERNATIONAL CONGRESS NUMBER.

EDITED BY GEORGE HOLMES,

SECRETARY OF THE INSTITUTION.

1898.

OFFICE: 5, ADELPHI TERRACE, LONDON, W.C.

SOLD BY HENRY SOTHERAN & CO., 37, PICCADILLY, LONDON, W.; AND 140, STRAND, LONDON, W.C.

[*All rights reserved.*]

ADVERTISEMENT.

THE INSTITUTION AS A BODY IS NOT RESPONSIBLE EITHER FOR THE STATEMENTS MADE OR FOR THE OPINIONS EXPRESSED IN THE FOLLOWING PAGES.

CONTENTS.

PAGE

List of Officers v

List of Honorary Members, Members, and Associates vi

Objects of the Institution xvii

Bye-Laws and Regulations xvii

List of Officers of the Congress and Members of the Reception Committee xxv

Introduction xxviii

Introductory Proceedings li

Hardened Plates and broken Projectiles. By Monsieur L. E. Bertin, Honorary Member . . 1
Discussion on the above Paper 22

Non-flammable Wood. By Charles E. Ellis, Associate 26
Discussion on the above Paper 30

A Review of the History and Progress of Marine Engineering in the Royal Navy and Mercantile Marine from the Foundation of the Institution of Naval Architects to the present Date. By Sir John Durston, K.C.B., R.N., Engineer-in-Chief of H.M. Navy; Vice-President. And J. T. Milton, Esq., Chief Engineer Surveyor of Lloyd's Register of Shipping; Member of Council . 35
Discussion on the above Paper 52

Water-tube Boilers in high-speed Ocean Steamers. By Monsieur P. Sigaudy, Member . . . 58
Discussion on the above Paper 62

Business Proceedings on Tuesday, July 6, 1897 66

On the Advances made in the mathematical Theory of Naval Architecture during the Existence of the Institution. By Sir Edward J. Reed, K.C.B., F.R.S.; Vice-President 67
Discussion on the above Paper 97

Danish Steam Railway Ferries and Ice-breaking Steamers. By Captain I. C. Tuxen, Director of Naval Construction and Engineering, Royal Danish Navy; Member 105
Discussion on the above Paper. 112

On graphic Aid in approximating Hull Weights. By J. Johnson, Esq., Member 116
Discussion on the above Paper 118

PAGE

Crank and other Shafts used in the Mercantile Marine. By G. W. Manuel, Esq., R.N.R., Member. 121

Discussion on the above Paper 129

On the Formation of Cavities in Water by Screw Propellers at high Speeds. By Sidney W. Barnaby, Esq., Member 139

Discussion on the above Paper 143

Experiments on the Nature of the surface Resistance in Pipes and on Ships. By Professor H. S. Hele-Shaw, LL.D., M.Inst.C.E. 145

Discussion on the above Paper 153

Concluding Proceedings 157

Nominal Index 163

OFFICERS OF THE INSTITUTION.

1897.

President.

* THE RIGHT HON. THE EARL OF HOPETOUN, G.C.M.G.

Past Presidents.

THE RIGHT HON. THE EARL OF RAVENSWORTH.
THE RIGHT HON. LORD BRASSEY, K.C.B., D.C.L.

Vice-Presidents.

H.R.H. THE DUKE OF SAXE-COBURG AND GOTHA, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., ADMIRAL OF THE FLEET.
THE RIGHT HON. THE EARL OF NORTHBROOK, G.C.S.I.
THE RIGHT HON. THE EARL OF RAVENSWORTH.
THE RIGHT HON. EARL SPENCER, K.G.
THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., F.R.S.
THE RIGHT HON. LORD GEORGE HAMILTON, M.P.
THE RIGHT HON. LORD JOHN HAY, G.C.B., ADMIRAL OF THE FLEET.
THE RIGHT HON. SIR JOHN DALRYMPLE-HAY, BART., K.C.B., D.C.L., F.R.S., ADMIRAL.
*SIR NATHANIEL BARNABY, K.C.B.
SIR FREDERICK J. BRAMWELL, BART., D.C.L., F.R.S.
*SIR JOHN DURSTON, ESQ., K.C.B., R.N.
SIR FREDERICK W. E. NICOLSON, BART., C.B., ADMIRAL.
*SIR EDWARD J. REED, K.C.B., F.R.S.
*SIR WILLIAM H. WHITE, K.C.B., LL.D., Sc.D., F.R.S.
SIR JAMES WRIGHT, C.B.
*F. K. BARNES, ESQ.
*JAMES DUNN, ESQ.
*FRANCIS ELGAR, ESQ., LL.D., F.R.S.
*BENJAMIN MARTELL, ESQ.
*HENRY MORGAN, ESQ.
GEORGE W. RENDEL, ESQ.
*JOHN I. THORNYCROFT, ESQ., F.R.S.
W. H. TINDALL, ESQ.
A. F. YARROW, ESQ.

Members of Council.

*PROFESSOR J. H. BILES.
WALTER BROCK, ESQ.
R. J. BUTLER, ESQ.
H. E. DEADMAN, ESQ.
*A. DENNY, ESQ.
SIR RAYLTON DIXON.
W. THEODORE DOXFORD, ESQ., M.P.
D. J. DUNLOP, ESQ.
J. MACFARLANE GRAY, ESQ.
SIR WILLIAM GRAY.
JAMES HAMILTON, ESQ.
R. H. HUMPHRYS, ESQ.
*JOHN INGLIS, ESQ.
SIR JAMES LAING.
*W. LAIRD, ESQ.
FRANK C. MARSHALL, ESQ.
*J. T. MILTON, ESQ.
*JOHN SCOTT, ESQ., C.B., F.R.S.E.
*A. E. SEATON, ESQ.
T. SOPER, ESQ.
G. STANBURY, ESQ.
J. RODGER THOMSON, ESQ.
*PHILIP WATTS, ESQ.
*HENRY H. WEST, ESQ.

Associate Members of Council.

JOHN CORRY, ESQ.
PROF. J. H. COTTERILL, M.A., F.R.S.
R. E. FROUDE, ESQ., F.R.S.
THOMAS H. ISMAY, ESQ.
PROF. VIVIAN B. LEWES, F.C.S., F.I.C.
REAR-ADMIRAL G. DIGBY MORANT.
REAR-ADMIRAL G. H. NOEL.
JAMES RILEY, ESQ.

Trustees.

THE RIGHT HON. THE EARL OF HOPETOUN, G.C.M.G.
SIR NATHANIEL BARNABY, K.C.B.
HENRY MORGAN, ESQ.
JOHN CORRY, ESQ.

Treasurer.

HENRY MORGAN, ESQ. (Vice-President).

Honorary Solicitors.

MESSRS. PARKER, GARRETT & Co., St. Michael's Rectory, Cornhill, E.C.

Secretary.

GEORGE HOLMES, ESQ.

Auditors.

MESSRS. BALL, BAKER, DEED, CORNISH & CO., Chartered Accountants, 1, GRESHAM BUILDINGS, E.C.

* Members of the House Committee.

LIST OF HONORARY MEMBERS, MEMBERS, AND ASSOCIATES.

Honorary Members.

Andresen, Herr J. B.
Bertin, Mons. E.
De Bussy, Mons. L.
Duperré, Vice-Admiral Charles, French Navy
Griscom, Clement A.
Kelvin, The Right Hon. Lord, G.C.V.O., F.R.S.
Melville, Commodore G., United States Navy
Palmella, His Grace the Duke of
Popoff, Admiral, Imperial Russian Navy
Ravensworth, The Right Hon. the Earl of (Past President and Vice-President)
Wales, H.R.H. Albert Edward, Prince of, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E.
William II., His I. and R. Majesty The German Emperor, King of Prussia, &c.
York, H.R.H. the Duke of, K.G., K.T., K.P.

Members.

Adamson, Alexander
Adamson, P. H.
Agnew, George Alexander
Aisbitt, Matthew W.
Albrecht, T.
Alchin, A. H.
Alder, W. G. B.
Allan, C. E.
Allan, J. M.
Allen, R. W.
Allen, William H.
Alley, Stephen
Allfrey, Edward R.
Allison, William
Anderson, Sir William, K.C.B., D.C.L., F.R.S.
Andreæ, John Beuker
Andrew, David
Andrews, James
Anselm, P.
Anthony, James
Apsey, John
Archer, Colin
Archer, W. D.
Armstrong, Robert
Arthur, H. P.
Artsayooloff, Constantine
Ash, Henry Horatio
Ashton, H. Harold
Atkinson, Edwin John
Attwood, E. L.
Austin, Samuel P.

Babcock-Irving, W.
Bailey, C. H.
Bain, James
Ball, Edwin
Barnaby, Sir Nathaniel, K.C.B. (Vice-President)
Barnaby, Sydney Walker
Barnes, Fredk. K. (Vice-President)
Barnes, W.
Barnett, J. Rennie
Barrett, Richard H.
Barry, F. W.
Barter, F.
Bartram, R. A.
Baskcomb, William B.
Bate, E. R.
Beadon, D. C.
Beaton, Edwin
Bedbrook, James Albert
Beldam, Asplan
Benjamin, Ludwig
Berendt, Maximilian
Bernardi, V.
Berrier-Fontaine, Marc
Berry, Edwin
Bettini, R.
Bevis, R. R.
Biles, Prof. J. Harvard (Mem. Council)

Bissett, J. D.
Black, David F.
Black, John
Black, Peter Blair
Blackett, Jos.
Blake, Arthur W.
Blake, Herbert P.
Blohm, Hermann A.
Blom, Hans A.
Boddy, John
Bone, William John
Booth, E. S.
Booth, R. W.
Borgstede, Edward
Bourn, John
Bourne, James J.
Bowie, A.
Bowles, Francis T.
Boyd, J. White
Boyd, William
Brace, George R.
Bredsdorff, T.
Bridges, Thomas H.
Broad, John Freeman
Brock, H. W.
Brock, Walter (Mem. Council)
Brodie, John
Brown, A. Betts
Brown, George
Brown, James
Brown, K. B.
Brown, Walter
Browne, Andrew
Browne, Sir B. C., D.C.L.
Bruce, William
Bruhn, J.
Buchanan, Charles
Buchanan, Colin
Buchanan, John H.
Buckwell, G. W.
Burmeister, Carl Christian
Burney, Charles E.
Bushell, C. A.
Bushell, Edward H.
Busley, Carl
Butler, R. J. (Mem. Council)
Byrne, St. Clare John

Caiger, E. J.
Caird, A.
Caird, Patrick T.
Caldwell, James
Callaway, H.
Campbell, Hartley
Cardwell, John H.
Carmichael, John
Carney, J. H.
Carson, R.
Carter, G. J.
Carter, W. C.
Carter, W. H.
Casey, James
Champness, Henry R.
Chilcott, William W.
Christie, John D.
Clark, George
Clark, Henry
Clark, James Stewart
Clarke, Harry
Clarke, Henry T.
Claussen, G. W.
Clauzel, Vicomte Gaston
Clover, M.
Cole, G. J.
Cole, Henry A. B.
Coleman, T. D.
Collard, James Ambrose
Collings, J. W.
Coltart, B. Clyde
Comerma, Andrés A., General
Common, John F. F.
Connell, Charles B.
Cooke, H. J.
Cooke, Robert
Cooke, Thomas H.
Coomber, E. N.
Cooper, Charles
Cooper, G. P.
Cooper, William
Coote, Arthur
Cöp, Huibert
Copeland, Charles John
Corkhill, W.
Cornish, Harry John
Cotsell, James
Courtier-Dutton, W. T.
Cox, W. R.
Craig, George Butt
Craig, R.
Craig, William Jeffers
Cramp, Charles Henry
Crawford, J. P.
Crichton, David
Crighton, Robert
Croll, David
Crompton, Thomas A.
Crookston, John G.
Croom, J. M.
Curtis, Frederick T. W.

Dales, F. C.
Daniel, A. J.
Dartnall, Harold John
Davidson, Daniel
Davidson, W.
Davies, L. G.
Davis, W. T.
Davison, A. J.
Day, G. C.
Daymard, Victor
De Rusett, Edwin W.
Deadman, Henry Edward (Mem. Council)
Deane, C. G.
Denny, Archibald (Mem. Council)
Denny, James
Denny, Leslie
Denny, Peter, jun.
Denton, William
Dickie, James
Dickinson, F. T.
Dickinson, John
Dickinson, William
Dietrich, Alfred A.
Dixon, Sir Raylton (Mem. Council)
Dobson, William
Dodd, Thomas James
Donald, James
Donaldson, John
Doxford, Charles D.
Doxford, Robert P.
Doxford, William Theodore, M.P. (Mem. Council)
Drake, L. H.
Drakenberg, J. A.
Du Sautoy, Charles
Dudgeon, Alexander John
Dudgeon, F. S.

Duff, Peter
Dugdale, W. H.
Duncan, The Hon. George, A.P.H.
Duncan, James
Duncan, John
Dunlop, David J. (Mem. Council)
Dunlop, J. G.
Dunn, James (Vice-President)
Durston, Sir John, K.C.B., R.N. (Vice-President)
Dyer, C. M. B.
Dyer, Prof. H., M.A., D.Sc.
Dykes, George
Dykes, James

Edminston, J. E.
Edwards, F.
Edwards, N. P.
Eeles, Robert
Elder, Alexander
Eldridge, George
Elgar, Francis, LL.D., F.R.S. (Vice-President)
Ellis, Joseph H.
Ellis, John James
Elmslie, John E.
Esplen, John
Esplen, William
Etherington, J.
Evans, John
Evans, Lewis
Evans, Neville
Evers, Georg Wilhelm

Fairlamb, A. E.
Farquhar, Robert
Faruffini, Major J., Royal Italian Navy
Fellows, H. M.
Fenwick, Clennell
Ferber, Edwin G.
Ferguson, John
Ferguson, William Russell
Ferrand, C.
Field, T. S.
Fife, William, jun.
Flannery, J. Fortescue, M.P.
Fletcher, R. G.
Flohr, Justus
Foley, Nelson
Ford, W. J.
Forster, Charles
Fothergill, John R.
Fowling, Charles H.
Fownes, H.
Fox, A. G.
Frear, H. P.
Frykholm, J. L.
Furneaux, John B.
Fustor, Nicolas

Garrick, J.G.
Garriock, William
Gearing, Ernest G.
Gibb, Andrew
Gilby, J. N.
Gilchrist, James
Gill, George W.
Gillies, David
Gillies, James
Good, Farrant
Goodall, Frank C.
Gordon, Alexander Milne
Goulaeff, E. E., Colonel, Imperial Russian Navy, F.R.S.N.A.
Gould, A. H.
Gourlay, H.
Gow, James
Gracie, A.
Graham, W.
Gravell, John
Gray, Alex.
Gray, John Macfarlane (Mem. Council)
Gray, Sir William (Mem. Council)
Grayson, H. Holdrege
Grayson, H. M.
Greene, W. S. Clayton
Gregson, Herbert B.
Griffiths, J. A.
Grundy, Joseph
Guild, James F.
Gwynne, John

Haack, Carl Rudolph Otto
Haig, Robert
Halket, James P.
Hall, Charles
Hall, John Percy
Hall, William, jun.
Hallett, J.
Hallett, John H.
Hamilton, Andrew
Hamilton, A. K.
Hamilton, James (Mem. Council)
Hamilton, John
Hand, Henry
Harman, Frederick B. M.
Harris, Anthony
Harris, Henry Graham
Harvey, Francis Hamill
Harvey, John Hamilton
Haswell, Charles H.
Haussmann, Boris
Hay, Arthur C.
Haynes, Benjamin
Hearson, Professor T. A.
Hebson, Douglas
Heck, John Henry
Heimbruck, General Baron Wladimir, Imperial Russian Navy
Heine, A.
Henderson, Andrew P.
Henderson, John
Hepburn, George
Herreshoff, John B.
Herreshoff, Nathaniel G.
Hesketh, Thomas
Hichborn, Philip
Higgs, William Berry
Highton, Francis W.
Hill, Maxwell
Hockaday, W. T.
Hodge, Rowland
Hök, Wilhelm C.
Holman, Hugh W.
Holmes, Samuel
Holst, Fritz E.
Holt, Alfred
Horn, Andrew
Horsburgh, Stewart G.
Houston, J. A.
Hovgaard, G. W., Lieut., R.D.N.
Howaldt, A. J. G.
Howaldt, G. F.
Howaldt, Hermann
Howard, J. T.
Howden, James

Hudson, C. E.
Hudson, John
Hudson, J., jun.
Huddy, J. B.
Hughes, John G.
Hughes, Thomas W. R.
Hughes, W. O.
Hull, Edwin
Hume, James Howden
Humphrys, R. H. (Mem. Council)
Hunter, G. B.
Hunter, James
Hutcheson, Archibald
Hutchinson, J. H.

Inglis, John (Mem. Council)
Inglis, John
Irving, John
Isaac, Percy L.
Isaacs, W.
Isakson, Karl J. A.

Jack, J. W.
Jackson, A. S.
Jackson, Peter
Jacobitti, F.
Jacobsen, Valdemar
James, M. C.
Jenkins, T. H.
Jobling, Joseph C.
Johns, H. E.
Johnson, Alex. B.
Johnson, Charles H.
Johnson, Johan
Johnson, Robert T.
Johnson, T. Allan
Johnston, David
Jones, A. L.
Jones, Charles
Jordan, Charles H.
Joy, David

Kafer, John C.
Kelson, George
Kelson, George Henry
Kennedy, Prof. Alex. B. W., F.R.S.
Kennedy, A. McAusland
Key, George Andrew
Killner, J.
King, Frank B.
King, James F.
Kinghorn, John G.
Kirby, Frank E.
Kitching, J. F.
Kneffl, Alois
Knight, George S., jun.
Kock, J.
Konishi, Shinzaburo
Kops, J. T. J. de Bruyn
Koutaynikoff, N. E., General
Kraft, F.
Kurobe, Hiroo

Lagane, A. J. A.
Laing, Andrew
Laing, Sir James (Mem. Council)
Laing, William
Laird, William (Mem. Council)
Langton, Alfred
Langtry, C.
Lannes, P.
Laurie, James
Laurie, L. G.
Laurie, W.
Lax, G. A.
Lemon, C. Powell
Lecointe, Albert
Lester, Henry E.
Lewis, Alfred David
Lewis, William
Linnard, J. H.
Linnington, Edward A.
Lilliehöök, H. H.
List, John
Lister, Francis H.
Lithgow, William T.
Littlejohns, W. G.
Livingston, James
Lobnitz, F.
Loviagin, Roman M.
Lowdon, John
Lowdon, Thomas
Luke, W. J.
Lutschaunig, Victor

MacColl, Hector
MacColl, Hugo
Maccoy, John
Macdonald, James F.
MacIlwaine, John H.
Mackenzie, James
Maxton, James
Mackie, W. A.
Mackintosh, A. R.
Mackrow, Clement
Mackrow, George C.
Mackrow, G. F.
MacLean, Sir Andrew
MacLean, Andrew, jun.
Macmillan, William
Maddison, Joshua
Maginnis, Arthur J.
Maier, Fritz F.
Maksimoff, B. B., Imperial Russian Navy
Manaira, G.
Manuel, George W.
Mares, George R.
Mares, Joseph D.
Marshall, Francis C., J.P. (Mem. Council)
Marshall, Frank T.
Marshall, James B.
Martell, Benjamin (Vice-President)
Martin, E. L.
Martin, W. H.
Martin-Davey, W.
Mason, George F.
Maurice, F.
Maxton, James
May, William Walker
Mayston, Robert
McAuslan, D.
McDougall, Niel
McFarlane, G.
McGregor, Josiah
McGregor, Peter
McIntyre, John, jun.
McIntyre, Matthew
McKechnie, James
McKellar, Duncan
McLachlan, John
McLaine, Alexander
McLaren, W.
McNeil, James
Meerten, H. Van
Mees, Govert J.

Meiklereid, David
Menzies, Thomas
Metcalf, John C.
Meyer, J. L.
Middendorf, F. L.
Middleton, R. A.
Millar, Jackson
Millar, Thomas
Miller, Adam
Mills, John
Milne, George
Milne, W. J.
Milton, E. J.
Milton, J. D.
Milton, J. T. (Mem. Council)
Mitchell, R.
Mitchell, Robert
Moffitt, Robert
Moir, James
Mollison, James
Monroe, Robert
Monroe, W.
Morcom, Alfred
Mordey, Mark
Morgan, David John
Morgan, Henry (Vice-President and Treasurer)
Morison, D. B.
Morison, W.
Morrin, R.
Morrish, S. W. Furze
Morton, Robert
Mudd, Thomas
Muir, J. E.
Muir, R. Home
Muir, Hugh
Mumme, Carl
Mumford, A. G.
Munn, Robert A.
Murray, Alexander
Murray, C. W.
Murray, Henry
Myles, David

Napier, Henry M.
Napier, John
Narbeth, J. H.
Nash, S. A. G.
Nicholas, David
Nichols, C. B.
Nicholson, B.
Nicol, George
Nicol, John
Nielsen, K., Captain
Nightscales, J. H.
Norman, W. H.
Normand, J. A.
Norris, A. E. F.
Norris, William James
Norton, Harold P.

Oglethorpe, W. A.
O'Halloran, Timothy
Oram, Henry J.
Orlando, Salvatore
Orr, Alexander Thomson
Orr, James
Orvis, W. H.
Oswald, A. L.
Oswald, Thomas Ridley

Palmer, William
Parkes, Henry
Parnall, Martyn
Paterson, John
Paterson, J. V.
Patterson, John Lewis
Pattison, Joseph
Paulsen, William
Payne, Arthur E.
Pearce, E. A. J.
Pearson, Frank H.
Peck, James J.
Penn, John, M.P.
Penny, R. H.
Perrett, Josiah R.
Petree, James
Pettigrew, John
Phillips, Thomas
Phillips, Walter
Phorson, Peter
Piaüd, Pierre Léon
Pierrard, A.
Pilcher, F. J.
Piper, J. R.
Pirrie, The Right Hon. W. J.
Plenty, E. P.
Pohl, R.
Pollock, David
Pollock, James
Pollock, John
Pope, G.
Popper, S.
Potter, George Herbert
Potter James Hugh
Potter, W. H.
Potts, Cuthbert
Pratten, W. J.
Prentice, John
Preston, John
Price, J.
Price, Thomas
Puga, Cayo
Purves, David
Purvis, Frank P.

Quelch, R. J.
Quiggin, Daniel A.

Radford, R. H.
Rait, Henry Milnes
Ramage, A. G.
Ramage, Richard
Ramsay, Charles T.
Ratnyk, Colonel Xaverius
Rauchfuss, Ernst
Read, John
Read, J. T., jun.
Readhead, James
Reavell, W.
Redman, Joseph F.
Reed, J. W.
Reed, Sir E. J., K.C.B., F.R.S. (Vice-President)
Reed, Thomas Alfred
Reeder, W. C.
Reid, James
Reid, J. Gardiner
Rendel, George W. (Vice-President)
Renner, W.
Rennie, George Banks
Rennie, J. K.
Renton, John
Reynold, C. H., jun.
Richards, A. E. G.

Richardson, Andrew
Richardson, J. Wigham
Rickard, G.
Ridley, J. T.
Riley, W. H.
Ritchie, Duncan Darroch
Ritson, Maurice
Ritson, Thomas S.
Roberts, William C.
Robertson, Duncan
Robertson, Ebenezer J.
Robertson, Graham
Robertson, Leslie S.
Robinson, J.
Robinson, Mark
Rodger, George
Rogers, Herbert M.
Rolland, Alexander
Roper, Leopold
Ropner, R., jun.
Roscoe, Harry
Roscoe, Peter Henry
Rota, Giuseppe
Rounthwaite, H. M.
Rowan, James
Rowell, Herbert
Royal, J. G.
Rubie, Charles Andrew F.
Rubie, George P.
Ruck-Keene, H. A.
Rudd, Charles
Ruggieri, A., Royal Italian Navy
Rule, J. G., Glasson
Rusden, Lowry
Russell, Joseph
Rutherford, Alex.

Sachsenberg, Gotthard
Sage, Charles
Salvesen, Henry A.
Sampson, John
Samson, P.
Samuda-Benthall, J. L.
Samuelson, Martin
Sandison, Magnus
Sawyer, F. H. R.
Scantlebury, E. R.
Schlick, Otto
Schnack, S. F. A.
Schneider, F. H. M. L.
Schneider, William M. F.
Schulz, R.
Schunke, Hugo
Scorer, G. S.
Scott, Charles C.
Scott, George
Scott, James Edward
Scott, John, C.B., F.R.S.E. (Mem. Council)
Scott, John
Scott, Robert S.
Scott, William
Seabrooke, A. W.
Seaton, Albert E. (Mem. Council)
See, Horace
Seebeck, Georg
Selfe, Norman
Sellar, James
Sells, Charles
Sells, Charles de Grave
Shand, Hinton
Shapcott, R. A.
Sharer, Edmund
Shearman, John
Shepherd, John William
Shield, Henry
Shilston, V. G.
Shiota, T.
Short, Joseph
Short, J. Y.
Shotton, J. W.
Sibbick, C.
Sibun, James
Sigaudy, P.
Simey, George H. T.
Simons, William
Simpson, Francis C.
Simpson, George
Sinclair, Peter Alexander
Sinclair, Russel
Skinner, James
Sloggett, Thomas Henry
Smith, C. E.
Smith, John
Smith, Wasteneys
Smith, W. E.
Soliani, Nabor, Colonel, Royal Italian Navy
Soper, Joseph M.
Soper, Thomas (Mem. Council)
Spear, John
Spears, F. P.
Spence, Henry Grant
Spence, J. A.
Spence, J. C.
Spyer, Arthur
Stahl, Albert W.
Stainer, George Henry, C.B.
Stanbury, George (Mem. Council)
Steele, Robert
Steele, W. R.
Stephen, A.
Stephen, F. J.
Stephenson, F.
Stewart, Alexander
Stewart, James
Stoddart, John E.
Stone, Douglas
Stoney, Bindon Blood
Storey, W. C.
Stratton, E. Platt
Stromeyer, C. E.
Strong, George H.
Stuelcken, J. C.
Summers, William
Swainston, W. H.
Swan, Henry Frederick
Swift, John Crane
Syme, James

Tatham, Stanley
Taylor, Alexander
Taylor, Benson
Taylor, D. W., U.S.N.
Taylor, John
Taylor, Peter
Tchernigovsky, P. E., Lt.-Colonel
Tennyson-d'Eyncourt, E. H.
Thayer, I. E.
Thearle, Samuel J. P.
Thom, John
Thompson, John Augustus
Thompson, J. E.
Thompson, J. L.
Thompson, Robert
Thompson, W. B.
Thomson, John
Thomson, Charles

Thomson, G. Paul
Thomson, J. Rodger (Mem. Council)
Thomson, James, M.A.
Thomson, J. M.
Thomson, R. H. B.
Thornycroft, J. I., F.R.S. (Vice-President)
Tierney, Edward J.
Tilburn, William Alexander
Timme, George A.
Todd, Thomas
Topp, Carl
Toropoff, A., General
Tower, Beauchamp
Trewent, Francis J.
Tritton, Seymour B.
Turk, Gerbrand
Turnbull, Thomas
Turpin, James
Tuxen, I. E., Captain, R.D.N.
Tweedy, John

Ullstrom, Otto

Valsecchi, Lieut.-Colonel Giuseppe, Royal Italian Navy
Viehoff, Jacobus M.
Vivet, Léon
Von Kodolitsch, F.
Voss, E. C. A.

Wadia, Bomanjee S.
Walker, George
Walker, John
Wallace, William
Wallace, W. Carlile
Walpole, Thomas
Walter, C. O. M.
Ward, John
Warder, G. E. E.
Warren, Ruben H.
Warren, T. Samuel
Watkins, Alfred
Watkins, William
Watson, George Lennox
Watson, Ralph
Watts, Philip (Mem. Council)
Weeks, Courtenay O.
Weighton, Robert L.
Weir, James
Welch, John Joseph
Welsh, T. M.
Wemyss, J. Leith
West, Ernest William
West, Henry H. (Mem. Council)
Westgarth, Tom
Westmacott, A.
Westwood, J., jun.
Wheatley, W. C.
White, John S.
White, R. Saxton
White, Sir William Henry, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President)
Whiting, William H.
Whyte, William
Widdas, Tom Dodd
Widmann, Daniel E.
Wildish, James George
Wilkins, J. Edwin
Wilkinson, Henri
Williams, Jesse
Williamson, James
Williamson, Robert
Wilson, Alexander Hall
Wilson, J. P.
Wilson, Robert
Wilson, Walter Henry
Wiltshire, George
Wimshurst, Henry Claudius
Wimshurst, J. E.
Wingfield, C. H.
Winstanley, P. D.
Withy, Henry
Wolff, Gustav W., M.P.
Woods, Arthur R. T.
Woodward, J. J.
Workman, Frank
Wotherspoon, John H.
Wright, Sir James, C.B. (Vice-President)
Wright, J. J.

Yamaki, Gonzaburo
Yarrow, A. F. (Vice-President)
Yates, James A.
Yeo, John
Young, J. Denholm
Young, Sidney
Young, W. Andrew
Younger, Archibald Scott, B.Sc.

Zeysing, Theodore, Imperial German Navy
Ziese, Carl H.
Ziese, Rudolf
Zimmermann, Robert

Associates.

Abel, Rudloph
Acland, W. A. D., Captain, R.N.
Adams, Edgar Tarry
Agius, Edgar
Agius, E. T.
Ailsa, The Most Hon. the Marquis of
Alliman, Albert
Amsler, Alfred, Dr.
Angier, Captain T. V. S.
Angove, W. C.
Armstrong, The Right Hon. Lord, C.B., D.C.L., F.R.S. (Vice-Pres.)
Armstrong, F. H., Lieut.-Colonel
Arnold, W. F. A.
Atkins, H. S.
Attridge, J. W.
Aukland, Thomas F.
Aynsley, C. Murray, C.B., Rear-Admiral
Baker, Lieut.-Col. R. Barrington
Bankson, Lloyd
Barnett, Samson
Barnwell, R.
Barraza, M., Capt. Argentine Navy
Barreto, Baron
Barrie, Charles
Barry, Sir J. Wolfe, K.C.B., F.R.S.
Baxter, W. J., U.S.N.
Bayford, J. J.

Beardmore, William
Becher, S. J.
Beldam, Robert
Bell, Jas.
Belleville, Louis Delaunay
Benham, H.
Beresford, Rear-Admiral the Right Hon. Lord Charles, C.B., M.P.
Bertram, Henry
Billinton, R. J.
Binney, William Hardman
Blackmore, Edward
Blundstone, Samuel R.
Blow, Walter George
Bowden-Smith, Sir N., Vice-Admiral, K.C.B.
Boys, Henry, Admiral
Bramwell, Sir Frederick, Bart., D.C.L., F.R.S. (Vice-President)
Brand, J. Arthur
Brassey, the Right Hon. Lord, K.C.B. (Past President)
Brassey, The Hon. Thomas A.
Brereton, C. A.
Brotherhood, Peter
Brown, A. H.
Brown, Joseph
Brunel, H. Marc
Bryant, Henry
Bullivant, W. P.
Burrell, George

Caird, J.
Cameron, Nelson
Caminos, Jacinto Z., Lieutenant, Argentine Navy
Campbell-Thompson, J.
Canter, William James, R.N.
Carlisle, J.
Carozzi, J. L.
Carr, Henry John, Rear-Admiral
Carttar, Edward Arundel
Chadburn, A. W.
Chapman, Henry
Chasseloup Laubat, le Marquis de
Chatfield, Alfred J., Rear-Admiral, C.B.
Chubb, Richard
Church, E. J., Rear-Admiral
Churchill, James D.
Clanchy, Henry Thomas
Clark, John
Clark, John A.
Clark, Lyonel E.
Cleghorn, Alexander
Cleveland, H. F., Rear-Admiral
Cobb, George H.
Cohan, E. A.
Cohen, Arthur, Q.C.
Cohn, A.
Collin, D.
Collis, T. J.
Colmer, G. W.
Colomb, P. H., Vice-Admiral
Colville, A.
Colwell, J. C., Lieut., U.S. Naval Attaché
Commerell, Admiral of the Fleet Sir J. E., G.C.B., V.C.
Cookes, T. S.
Cooper, H.
Cooper, J. H., Colonel
Corry, John (Assoc. Mem. Council)
Cotterill, Professor J. H., M.A., F.R.S. (Assoc. Mem. Council)
Craddock, T. F.
Crease, John Frederick, Maj.-Gen., R.M.A., C.B.
Crofton, Edward
Cross, William
Crow, A. H.
Crowder, W., Captain
Cullen, P., Captain
Custance, Reginald, Captain, R.N.

Da Costa, S. J.
Davies, Arthur Capel
Davis, A. H.
De Cuverville, J. De Cavelier, Le Vice-Amiral, French Navy
De Horsey, Algernon F.R., Admiral
De Salis, H. R.
Dempster, John
Denny, John M., M.P.
Depree, A. O.
Devine, W. H.
Dickinson, C. F.
Dillon, Malcolm
Dixon, H. Raylton
Dixon, James
Dodd, J. B.
Domoney, J. W.
Donald, James A.
Donaldson, Thornycroft
Donaldson, William A.
Donnelly, Patrick James
Donkin, Richard Sims, M.P.
Dove, E. J.
Doxford, Robert
Dryhurst, A. G.
Duncker, Arthur
Dunlop, Robert Jack
Dvorkovitz, Paul

Wilmot, S. Eardley, Captain, R.N.
Eckart, William R., C.E.
Edye, John Alfred
Eidlitz, Leopold, jun.
Ellis, Chas. Ed.
Ellis, W. H. M.
Emory, W. H., Lieut.-Commander, U.S.N.
Epes, H. S.
Etheridge, C. K.
Etherington, John A. E.
Evans, David
Evans, Frederick R.

Fairfax, Joseph S.
Fanshawe, Sir Edward Gennys, G.C.B., Admiral
Fenwick, J. Fenwick
FitzGerald, C. C. P., Rear-Admiral
Fitzgerald, D. W.
Flemmich, G. F.
Foster, J. W.
Fowler, Sir John, Bart., K.C.M.G., F.R.S.
Fox, A. William
Fox, Samson
Fradgley, J. B.
Fraissinet, Alfred
Fremantle, Vice-Admiral the Hon. Sir E. R., K.C.B., C.M.G.
Froud, A. S.
Froude, R. E., F.R.S. (Assoc. Mem. Council)

Garcia, D. C., Lieut. Argentiné Navy
Gardner, P.
Garrett, S.
Gervais, A., Admiral, French Navy
Gilchrist, Percy C.
Giuliani, José
Glenfield, F.
Gordon, C. W.
Gordon, Robert
Gough, Kedgwin E. K.
Grainger, Thomas L., Captain
Graves, W. T.
Green, W. Miall
Greenhill, Alfred George, Professor, F.R.S.
Grigorovitch, J., Captain
Gross, Felix
Groves, James
Gülich, E., Captain, I. German Naval Attaché
Guppy, Thos. R.

Hadfield, R. A.
Hamilton, The Right Hon. Lord George, M.P. (Vice-President)
Harfield, William Horatio
Harper, G. T.
Hartmann, August
Hartmann, George
Hartmann, Wilhelm
Hay, James M.
Hay, The Right Hon. Lord John, G.C.B., Admiral of the Fleet (Vice-President)
Hay, The Right Hon. Sir John Dalrymple-,Bart.,K.C.B.,D.C.L., F.R.S., Admiral (Vice-President)
Head, H.
Healey, Edward C.
Heidmann, Robert Woldemar
Heidmann, T. H.
Henderson, George T.
Hibbs, F. W.
Hick, Thomas
Hill, E. J.
Hill, Sir E. S., Colonel, K.C.B., M.P.
Hills, Arnold F.
Hodges, Petronius
Hodgkinson, George
Hodd, Thos. H.
Hogarth, A. P.
Holland, Arthur, M.A.
Holland, S. C., Captain, R.N.
Holzapfel, A. C. A.
Holzapfel, Max
Hope, L. C.
Hopetoun, The Right Hon. the Earl of, G.C.M.G. (President)
Hopkins, Sir John Ommaney, Vice-Admiral, K.C.B.
Houlder, A. F.
Houldsworth, William
Howard, J. William
Howell, J. Bennett
Hoyle, J. Rossiter
Hozier, H. M., Colonel, C.B.
Huddart, James
Hume, Washington
Hume, W. C.
Hunsiker, Millard
Hurndall, W. F.
Hutchinson, Walter E.

Ihlen, Nils, Admiral, Royal Norwegian Navy
Ismay, J. Bruce
Ismay, Thomas H. (Assoc. Mem. Council)
Ivanoff, N., Colonel, Imperial Russian Navy

Jack, Thomas
Jackson, J. E., Captain
Jacobi, Carl Adolph
Jacobi, Ernst
James, J. M.
Japp, John
Jaques, W. H., late United States Navy
Jarman, Stephen, R.N.R.
Jedina, The Chevalier L. de, Captain, I. and R. Austro-Hungarian Navy
Johnson, Arthur
Johnstone, Lieut. George, R.N.R.
Jullien, M.

Keller, Francis
Kelly, Alexander
Kemp, Dixon
Kestranek, W.
Kettelwell, A. S.
King, Percy Liston
Kirkaldy, John
Kirkaldy, Thomas
Knaudt, Otto
Knott, James
Knudson, Gunnar
Kriloff, Captain A. N., Imperial Russian Navy
Kröller, A. G.

Laeisz, C. Ferd.
Lagerwall, J. M., Captain, Royal Swedish Navy
Lambert, Professor Carlton J.
Lambton, Captain the Hon. Hedworth
Langridge, Henry
Latorre, Juan José, Rear-Admiral Chilian Navy
Laws, George A.
Laws, G. Umfreville
Lawson, William Robert
Le Doux, Richard
Lee, William, Esq.
Leflaive, L. J. G.
Lewes, Professor Vivian B., F.I.C., F.C.S. (Assoc. Mem. Council)
Lightfoot, T. B.
Likhatchof, J., Vice-Admiral. Imperial Russian Navy
Linley, A.
Linley, Joseph A.
Lister, W. N., Lieut., R.N.R.
Little, Henry W.
Littleboy, C. W.
Lloyd, Com. E. W., R.N.
Lloyd, R. Samuel
Long, A. E.
Lund, William
Lyell, F. H.
Lyle, R. P.

MacDonnell, Alexander
MacDougall, Dugald
MacIlwraith, A.
Mackay, Sir J. L., K.C.I.E.
Marr, James
Martin, E. P.
Martin, W. Tyson
Martino, The Chevalier Eduardo de
Massey, W. A.
McCalmont, H. L. B., M.P.
McGregor, Allan Gow
McIntyre, John
Mechan, H.
Metcalfe, John
Meyer, John
Milburn, J. D.
Miller, Gordon
Montgomery-Moore, A. W.
Moore, W. J. P.
Morant, George Digby, Vice-Admiral (Assoc. Mem. Council)
Morrison, James
Mullan, F. C.

Napier, James, M.A., F.R.S.E.
Neal, William George
Neilson, John
Nelson, T. H.
Newey, Capt. Samuel C.
Newman, A. R.
Nicholl, E.
Nicolson, Sir Frederick W. E., Bart., C.B., Admiral (Vice-President)
Niven, O. B., Com.
Niven, W. D., C.B., F.R.S.
Noad, Lewis.
Noel, G. H., Rear-Admiral (Assoc. Mem. Council)
Northbrook, The Right Hon. the Earl of, G.C.S.I. (Vice-President)

O'Connor, C.

Panton, Charles E.
Park, J. Smith
Parker, J. Henry
Parsons, P. R.
Pascoe, J. R.
Pearce, Sir William G., Bart., M.A., LL.B.
Pembroke, Sydney
Pendred, Loughnan St. Lawrence
Perkins, James
Perkins, T.
Petersen, Otto L.
Petersen, William
Pharo, Jacob C.
Pilcher, Percy S.
Pile, Charles H.
Pinkney, Thomas
Pitt, Captain F. J., R.N.
Plater, H. R. F.
Pover, W. T.
Pratt, G. H. F.
Prendiville, John Edward
Price, Arthur, R.N.
Preston, F. G. Panizzi
Preston, H. W.
Putnam, Thos.

Ratliffe, G.
Ravier, Sylvain Louis
Rawson, Robert, Hon. Mem. Manchester Literary and Philosophical Society
Reincke, R. Leopold H.
Renwick, George
Reynolds, Edward Parker
Richardson, Sir Thomas, M.P.
Ridley, John H.
Riley, James (Assoc. Mem. Council)
Ritson, Arthur
Robson, George
Rogestvensky, Capt. Z., I.R.N.
Rosenthal, J. H.
Roseti, Lieut.-Com. G. S., Argentine Navy
Ross, William Henry Russel
Rothe, H. P., Commodore, Danish Royal Navy
Rowley, Charles J., Admiral
Rugg, C. H.
Ruhm, T. S.
Russell, A. G.
Saborido, Lieut. L., Argentine Navy
Sachs, E. O.
Samuelson, Sir Bernhard, Bart., F.R.S.
Sanders, Ludwig
Sankey, Captain M. H. P. Rial, R.E. (retired)
Sarjeant, W. F.
Saunders, James Ebenezer
Saxe-Coburg and Gotha, H.R.H. the Duke of, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet (Vice-President)
Scantlebury, Vincent John
Schlutow, Albert
Schwanhausser, W.
Scott, Colin W.
Scott, Ernest
Scott, George J.
Seaman, Charles J.
Semler, Johannes
Serena, Arthur
Seymour, Vice-Admiral Sir Edward Hobart, K.C.B.
Sinclair, D.
Singer, F. M.
Sloan, W.
Smith, R. Knightly
Smitton, Frederick Harrison
Spencer, Right Hon. Earl, K.G. (Vice-President)
Spencer, John W.
Starnes, J. S.
Stephens, Thomas Walls
Stewart, Andrew
Stewart, J. G.
Stewart, Walter J. L.
Stileman, F.
Stoker, R. B.
Suart, A.
Sutherland, Sir Thomas, G.C.M.G., M.P.
Sztranyavszky, L. von, Commander, I. and R. Austro-Hungarian Naval Attaché

Tagg, George John
Tamplin, F. A.

Tamplin, T. Ward
Tapscott, G. L.
Tate, R.
Taylor, George W.
Taylor, W. Isaac
Temperley, Joseph
Terry, Stephen H.
Thomasson, Lucas
Thompson, Stephen
Thomson, Andrew
Thornycroft, J. E.
Thubron, E. Blakelock
Thurston, Robert H., Professor
Tiedeman, Carl
Tindall, William H. (Vice-President)
Todd, J. Stanley
Trotter, T., Captain

Uribe, Luis, Rear-Admiral, Chilian Navy
Urtubey, Clodomiro, Rear-Admiral, Argentine Navy
Utley, T.

Van Raalte, J.
Vassilioff, S.
Vavasseur, Josiah
Vickers, A.
Vogelsang, Alexander

Wade, W. S.
Wait, A. M.
Walker, W., Colonel, V.D., J.P.
Watkinson, W. H., Professor
Watson, H. Burnett
Watson, Henry James
Watson, W.
Watson, William
Watt, John
Watts, Edmund H.
Watts, Fenwick Shadforth
Webster, M. P.
Wedgwood, J. C.
Weidemann, Christopher
Westmacott, Percy G. B.
Wharton, Sir William J. L., Rear-Admiral, K.C.B., F.R.S.
White, J. Bell

White, Robert
Wiegand, H.
Willard, C. D.
Williams, R. W.
Williams, Samuel
Williamson, R. H
Wills, W.
Wilson, A.
Wilson, A. K., Rear-Admiral, V.C., C.B.
Wilson, H. C.
Wilson, W. G.
Wingfield, G. J., Com. R.N.
Wise, William Lloyd
Woodall, J. W.
Wort, W. E.
Wylie, R.

Yamamoto, N.
Younger, Robert L.

Ziffer, J. H.

OBJECTS OF THE INSTITUTION.

THE objects of the INSTITUTION OF NAVAL ARCHITECTS—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. THE INSTITUTION OF NAVAL ARCHITECTS shall consist of three classes, viz., Members, Associates, and Honorary Members.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

5. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

6. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

7. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

8. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

9. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

10. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

11. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

12. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

13. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

14. *Members of Council.*—Members only shall be eligible for election as Members of Council at the Annual General Meeting.

15. *Associate Members of Council.*—Associates only shall be eligible for election as Associate Members of Council at the Annual General Meeting.

16. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

17. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum*.

18. The Council may appoint Committees to report to them upon special subjects.

19. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

20. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

21. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

22. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution,

23. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

24. *Trustees.*—There shall be four Trustees, two of whom shall be the President and Treasurer of the Institution for the time being. The remaining two shall be appointed by, and hold office at the pleasure of the Council. In the names of these trustees, under the direction of the Council of the Institution, all securities shall be taken and investments made, the whole of such property being notwithstanding subject to the disposition of the Council, and the order of the Council in writing, signed by the Chairman of the Meeting and countersigned by the Secretary, shall be obligatory upon and full authority for the Trustees.

25. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

26. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

27. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

29. In each year six Ordinary and two Associate Members of Council shall retire, unless before the date of drawing up the Balloting Lists for the election of the Council any Members of the Council shall have died or resigned, in which case only so many members shall retire as shall be necessary in order to make up the number to six Ordinary and two Associate Members of Council, subject always to the provisions of Rule 86. The Members who shall retire in each year shall be those who have served longest on the Council from the date of the last election, and in the event of there being several Members who have served an equal time on the Council, the order of retirement amongst these shall be alphabetical. The retiring Members shall be eligible for re-election.

30. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely :—

1*st.* A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2*nd.* A list of candidates to fill any vacancies in the list of Vice-Presidents that it may be intended to fill up from among the professional Members of the Institution.

3*rd.* Lists for the election of the Ordinary Members and Associate Members of Council.

31. No addition shall be made to the list of Vice-Presidents until, by death or resignation, their number shall have been reduced to below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. The vacancies are to be filled up in such a manner that not less than one-half nor more than two-thirds of the total list of Vice-Presidents shall be professional Members of the Institution. Provided

always that the Council shall be at liberty, should special circumstances arise before the numbers shall have been reduced below twenty-four, to provide for the election of one Member and one Associate of the Institution as Vice-Presidents.

32. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of a professional Member of the Institution, the election shall be by voting papers issued to all Members of the Institution. The candidates to fill the vacancy shall be selected by the Council in the month of January from among the existing or past Members of Council. The number of candidates shall not be less than two for each vacancy, but shall not otherwise be limited. The voting papers shall be issued to the members at the same time as the voting papers for the election of Members of Council, and shall be subject to the same regulations and scrutiny as these latter, as provided for by Rules 37, 38, 39, 40.

33. After having been once elected by voting papers, the Vice-Presidents will be subject to re-election every year in a body at the Annual Meetings.

34. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of an Associate of the Institution, the nomination to fill the vacancy shall be made by the Council, and the candidate nominated shall be included in the list of Vice-Presidents submitted at the Annual Meetings for election in a body.

35. No addition shall be made to the total number of Ordinary Members of the Council until, by death of resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

36. At the date of issuing the Syllabus of the Annual General Meetings in each year, the Lists proposed by the Council for the election of Members to fill the vacancies in the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the retiring Ordinary Members of Council at the time of the preparation of the Balloting List, together with as many new names of Members of the Institution as shall be needed to bring the number up to twice the number of vacancies, and the whole of these names shall be printed in alphabetical order. Secondly, the names of the retiring Associate Members of Council at the time of the preparation of the Balloting List, together with as many new names of Associates of the Institution as shall be needed to bring the number up to twice the number of vacancies, and these names also shall be printed in alphabetical order. From these Lists the vacancies in the Council shall be filled up. Every Member shall be at liberty to vote for as many names on each of the Lists as there are vacancies to be filled, but not for more.

37. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to vote for as many names on that List as there are vacancies to be filled, but not for more.

38. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

39. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall then nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council ; and

(5) The Scrutineers shall receive all Ballot Papers which may have reached the Secretary, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes ; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected, provided always that the List does not contain more names than there are vacancies to be filled. If, in consequence of two or more of the candidates receiving an equal number of votes, the List shall contain more names than there are vacancies, the Council shall, at their next meeting, decide which of these candidates shall be elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

40. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

41. In the event of any vacancy occurring in the offices of either President or Treasurer after the date of the Annual Election in any year, the Council shall have power to elect a new President or Treasurer as the case may be, who shall hold office till the conclusion of the next Annual General (Spring) Meeting of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

42. Any Member, Associate, or Honorary Member, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A. ; Assoc. I.N.A. ; Hon. Mem. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

43. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be

signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

44. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

45. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

46. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

47. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

48. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

49. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

50. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

51. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

52. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

53. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

54. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

55. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

56. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

57. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

58. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

59. Members and Associates are particularly requested to communicate to the Secretary any change of address.

LIST OF OFFICERS OF THE CONGRESS AND MEMBERS OF THE RECEPTION COMMITTEE OF THE INTERNATIONAL CONGRESS OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

Honorary President:

H.R.H. THE PRINCE OF WALES, K.G., HON. ADMIRAL OF THE FLEET.

Honorary Vice-Presidents:

H.R.H. THE DUKE OF SAXE-COBURG AND GOTHA, K.G., ADMIRAL OF THE FLEET.
H.R.H. THE DUKE OF YORK, K.G., CAPTAIN R.N.
THE RIGHT HON. GEORGE J. GOSCHEN, M.P., FIRST LORD OF THE ADMIRALTY.
THE RIGHT HON. C. T. RITCHIE, M.P., PRESIDENT OF THE BOARD OF TRADE.

President:

THE RIGHT HON. THE EARL OF HOPETOUN, G.C.M.G., CHAIRMAN.

Members of the Reception Committee:

The Right Hon. the EARL OF HOPETOUN, G.C.M.G., Chairman.

A. Adamson, Esq.
W. H. Allen, Esq.
J. G. S. Anderson, Esq.
Captain T. V. S. Angier.
The Right Hon. Lord Armstrong, C.B., D.C.L., F.R.S.
J. Bain, Esq.
Sir N. Barnaby, K.C.B.
F. K. Barnes, Esq.
Charles Barrie, Esq.
W. Beardmore, Esq.
S. J. Becher, Esq.
Rear-Admiral the Right Hon. Lord Charles Beresford, C.B., M.P.
Professor J. H. Biles.
W. J. Bone, Esq.
J. W. Boyd, Esq.
Admiral H. Boys.
Sir Frederick J. Bramwell, Bart., D.C.L., F.R.S.
The Right Hon. Lord Brassey, K.C.B., D.C.L.
The Hon. T. A. Brassey.
Walter Brock, Esq.
R. J. Butler, Esq.
James Casey, Esq.
H. Chapman, Esq.
Rear-Admiral Church.
George Clark, Esq.
Vice-Admiral Cleveland.
Vice-Admiral P. H. Colomb.
Admiral of the Fleet Sir J. E. Commerell, V.C., G.C.B.
A. Coote, Esq.
J. T. Corner, Esq.
H. J. Cornish, Esq.
John Corry, Esq.
Professor J. H. Cotterill, F.R.S.
Sir Donald Currie, G.C.M.G., M.P.
Sir Edwyn Sandys Dawes, G.C.M.G.
L. G. Davies, Esq.
H. E. Deadman, Esq.
A. Denny, Esq.
John Denny, Esq., M.P.
James Dixon, Esq.
Sir Raylton Dixon.
J. Donaldson, Esq.
W. T. Doxford, Esq., M.P.
D. J. Dunlop, Esq.
The Most Noble the Marquis of Dufferin and Ava, K.P., G.C.M.G., G.C.I.E., F.R.S.
J. Dunn, Esq.
Sir A. Durston, K.C.B., R.N.
Captain S. Eardley-Wilmot, R.N.

F. Elgar, Esq., LL.D., F.R.S.
C. E. Ellis, Esq.
W. H. M. Ellis, Esq.
Rear-Admiral C. C. P. Fitzgerald.
J. Fortescue Flannery, Esq., M.P.
J. Fothergill, Esq.
R. E. Froude, Esq., F.R.S.
Sir Christopher Furness.
S. Garrett, Esq.
E. Gearing, Esq.
P. C. Gilchrist, Esq.
The Hon. the Lord Provost of Glasgow.
J. Gravell, Esq.
J. Macfarlane Gray, Esq.
The Right Hon. Lord George Hamilton, M.P.
James Hamilton, Esq.
G. T. Harper, Esq.
H. G. Harris, Esq.
W. Hartmann, Esq.
Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S,
E. C. Healey, Esq.
Sir William Henderson, LL.D.
G. Hepburn, Esq.
A. F. Hills, Esq.
A. Holt, Esq.
S. G. Horsburgh, Esq.
W. E. Hubbard, Esq.
R. H. Humphrys, Esq.
G. B. Hunter, Esq.
John Inglis, Esq.
T. H. Ismay, Esq.
C. Jones, Esq.
The Right Hon. Lord Kelvin, G.C.V.O., F.R.S.
Dixon Kemp, Esq.
Professor A. B. W. Kennedy, F.R.S.
Sir James Laing.
W. Laird, Esq.
Professor V. B. Lewes, F.C.S., F.I.C.
W. T. Lithgow, Esq.
The Right Hon. the Lord Mayor of London.
H. L. B. McCalmont, Esq., M.P.
D. MacDougall, Esq.
G. W. Manuel, Esq.
F. C. Marshall, Esq.
B. Martell, Esq.
J. T. Milton, Esq.
Vice-Admiral G. Digby Morant.
A. Morcom, Esq.
H. Morgan, Esq.
Thomas Mudd, Esq.
H. M. Napier, Esq.
Sir Andrew Noble, K.C.B.
Rear-Admiral G. Noel.
The Right Hon. the Earl of Northbrook, G.C.S.I.
Hubert Parry, Esq., Mus. Doc.
Sir William Pearce, Bart., M.A., LL.B.
J. Penn, Esq., M.P.
The Right Hon. W. J. Pirrie.
Thomas Putnam, Esq.
H. M. Rait, Esq.
The Right Hon. the Earl of Ravensworth.
John Read, jun., Esq.
Sir E. J. Reed, K.C.B., F.R.S.
G. B. Rennie, Esq.
G. Renwick, Esq.
Rear-Admiral E. Rice.
T. Richardson, Esq., M.P.
W. Richardson, Esq.
James Riley, Esq.
Mark Robinson, Esq.
R. Ropner, jun., Esq.
Admiral C. J. Rowley, R.N.
C. H. Rugg, Esq.
J. Sampson, Esq.
C. Du Sautoy, Esq.
C. W. Scott, Esq.
John Scott, Esq., C.B., F.R.S.E.
A. E. Seaton, Esq.
Arthur Serena, Esq.
Vice-Admiral Sir N. Bowden Smith, K.C.B.
T. Soper, Esq.
Frederick R. Spark, Esq., J.P.
H. G. Spence, Esq.
The Right Hon. the Earl Spencer, K.G.
J. W. Spencer, Esq.
G. Stanbury, Esq.
C. Villiers Stanford, Esq., D.C.L.
W. Summers, Esq.
Sir Thomas Sutherland, G.C.M.G., M.P.
H. F. Swan, Esq.
Colonel du Plat Taylor, C.B.
G. W. Taylor, Esq.
Robert Thompson, Esq.
Archibald Thomson, Esq.
J. Rodger Thomson, Esq.
J. I. Thornycroft, Esq., F.R.S.
W. H. Tindall, Esq.
J. Tweedy, Esq.
Philip Watts, Esq.
H. H. West, Esq.
P. Westmacott, Esq.
Sir William White, K.C.B., Sc.D., LL.D., F.R.S.
J. G. Wildish, Esq.
J. Williamson, Esq.
W. H. Williams, Esq.
Rear-Admiral A. K. Wilson, V.C., C.B.
W. Lloyd Wise, Esq.
G. W. Wolff, Esq., M.P.
F. Workman, Esq.
Sir James Wright, C.B.
A. F. Yarrow, Esq.
J. A. Yates, Esq.
Sydney Young, Esq.

Executive Committee:

The Right Hon. the EARL OF HOPETOUN, G.C.M.G., Chairman.

Sir Nathaniel Barnaby, K.C B.
Admiral of the Fleet Sir J. E. Commerell, V.C., G.C.B.
John Corry, Esq.
Sir Donald Currie, G.C.M.G., M.P.
A. Denny, Esq.
Sir Raylton Dixon.
J. Dunn, Esq.
Sir A. Durston, K.C.B., R.N.
F. Elgar, Esq., LL.D., F.R.S.
A. F. Hills, Esq.
B. Martell, Esq.
H. Morgan, Esq.
Sir E. J. Reed, K.C.B., F.R.S.
Sir Thomas Sutherland, G.C.M.G., M.P.
Colonel du Plat Taylor, C.B.
J. I. Thornycroft, Esq., F.R.S.
Philip Watts, Esq.
Sir William White, K.C.B., Sc.D., LL.D., F.R.S.
J. Williamson, Esq.
A. F. Yarrow, Esq.

Treasurers of the Congress:

T. ELGAR, Esq., LL.D., F.R.S. | H. MORGAN, Esq.

Secretary of the Congress:

GEORGE HOLMES, Esq.

THE INTERNATIONAL CONGRESS OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

1897.

INTRODUCTION.

THE Council of the Institution of Naval Architects, instead of holding an ordinary Summer Meeting in the sixtieth year of the reign of Her Majesty the Queen, determined to celebrate the event by convoking an International Congress of Naval Architects and Marine Engineers in London, and to invite thereto, as guests, representatives from the Ministries of Marine of all the principal Naval Powers of the world, the foreign Societies having kindred objects to those of this Institution, the Committees who received this Institution with so much hospitality in Paris in the year 1895, and in Hamburg and Berlin in the following year, and, also, all the foreign Members of the Institution.

H.R.H. the Prince of Wales was invited to become Honorary President of the Congress, and graciously acceded to the request, and fixed on Tuesday, July 6, as the date on which he would formally open the meetings.

Their Royal Highnesses the Duke of Saxe-Coburg and the Duke of York, and also the Right Hon. George J. Goschen, M.P., First Lord of the Admiralty, and the Right Hon. C. T. Ritchie, M.P., President of the Board of Trade, were invited to become Honorary Vice-Presidents, and in each case most kindly accepted the invitation.

The Right Hon. the Earl of Hopetoun, G.C.M.G., President of the Institution of Naval Architects, was invited to become President of the Congress and Chairman of the Reception Committee.

The Vice-Presidents, Members, and Associate Members of the Council, and many representative Members and Associates of the Institution, and gentlemen connected with the Royal Navy and the shipbuilding, shipowning, and marine engineering professions outside the Institution, and also the Right Hon. the Lord Mayor of London, Sir J. Faudel-Phillips, Bart., G.C.I.E., and the Hon. the Lord Provost Richmond of Glasgow, were invited to join the Reception Committee.

A complete list of the officers of the Congress and of the members of the Reception Committee will be found on pages xxv. to xxvii.

The Reception Committee invited the Members and Associates of the Institution to subscribe to a fund for defraying the special expenses of the Congress. This invitation was most warmly responded to, and an ample fund was raised for the purpose referred to.

The President and Governing Body of the Imperial Institute kindly agreed to reserve the use of their Great Hall and East Conference Room, together with reading and writing rooms, for the meetings of the Congress.

The following Programme of meetings, excursions, and entertainments for the Congress, together with explanatory directions, was drawn up and carried out in its entirety :—

MONDAY, JULY 5.

9.30 P.M.—CONVERSAZIONE at the Hotel Cecil, Strand, W.C.

The Grand and Victoria Halls will be used for the purposes of the Conversazione. The Refreshments will be served in the latter hall. Entrance in the East Wing of the Hotel. The string band of the Royal Artillery will play during the evening by kind permission of the Commanding Officer. The Guests and Members will be received by the President and Council of the Institution of Naval Architects, commencing at 9.30 p.m. Evening dress.

TUESDAY, JULY 6.

FORMAL OPENING OF THE CONGRESS by H.R.H. THE PRINCE OF WALES, K.G., Hon. President.

By kind permission of H.R.H. the President and Governing Body of the Imperial Institute the Meetings for the Reading and Discussion of Papers will be held in the Great Hall and East Conference Hall of the Imperial Institute, South Kensington.

Approach by the Central Entrance. The badges will admit Ladies and Members of the Congress to the Imperial Institute during July 6 and 7.

Included in the accommodation provided, in addition to the Halls for the reading and discussion of papers, are the following rooms, viz.—a *Poste Restante* to which Members' letters may be addressed, a writing-room, a cloak-room, and lavatories.

11 A.M.—RECEPTION OF THE FOREIGN REPRESENTATIVES TO THE CONGRESS, AND OF THE GUESTS, in the Vestibule of the Institute, by the EARL OF HOPETOUN, G.C.M.G., President: and by the Reception Committee of the Congress.

N.B.—Members of the Institution of Naval Architects who are neither Foreign Representatives nor Members of the Reception Committee, are requested on arrival to pass *round* the Vestibule by the roped-off passages and to take their seats in the Great Hall.

The Foreign Representatives, after reception, are requested to pass *through* the Vestibule, and to take the seats reserved for them in the Great Hall.

11.30 A.M.—RECEPTION OF H.R.H. THE PRINCE OF WALES, K.G., Hon. President of the Congress, by the President and the Reception Committee. H.R.H. the Hon. President, attended by the President and the Reception Committee, will then proceed to the Great Hall, and there deliver a Speech of Welcome.

2. The First Lord of the Admiralty, the Right Hon. GEORGE J. GOSCHEN, M.P., will then deliver an Address, which will be followed by the Inaugural Address of the President of the Congress, the Right Hon. the EARL OF HOPETOUN, G.C.M.G.

The Meeting will then divide. Those present who intend to take part in the discussion of the papers in the East Conference Hall will proceed to the Hall, while the remainder will retain their seats. As far as possible, the papers read in the East Conference Hall are confined to the subject of Marine Engineering.

The following papers will then be read and discussed :—

IN THE GREAT HALL.

1. "*Hardened Armour Plates and broken Projectiles.*" By Monsieur EMILE BERTIN, Directeur des Constructions Navales, Ministry of Marine, Paris, Hon. Member I.N.A.

2. "*Non-flammable Wood.*" By C. ELLIS, Esq., Managing Director Sir John Brown & Co., Limited, Associate I.N.A.

IN THE EAST CONFERENCE HALL.

1. "*A Review of the History and Progress of Marine Engineering in the Royal Navy and Mercantile Marine from the Foundation of the Institution of Naval Architects to the present Date.*" By Sir JOHN DURSTON, K.C.B., R.N., Engineer-in-Chief of the Navy, Vice-President I.N.A.; and J. T. MILTON, Esq., Chief Engineer Surveyor Lloyd's Register of Shipping, Member of Council I.N.A.

2. "*Water-tube Boilers in high-speed Ocean Steamers.*" By Monsieur PIERRE SIGAUDY, Member I.N.A.

2 P.M.—COLD LUNCHEON in the East Garden and Pavilion at the Imperial Institute.

3 P.M.—Business Meeting of the Members and Associates of the Institution of Naval Architects only, in the Great Hall, for the election of New Members and Associates.

During the afternoon the Yachting and Fisheries Exhibition, in the galleries of the Imperial Institute, will be visited.

9 P.M.—RECEPTION at the Mansion House by the Lord Mayor and Lady Mayoress.

WEDNESDAY, JULY 7.

10 A.M.—MEETING in the Imperial Institute for the reading and discussion of papers.

The following papers will be read and discussed :—

IN THE GREAT HALL.

1. "*On the Advancement of the mathematical Theory of Naval Architecture during the Existence of the Institution of Naval Architects.*" By Sir EDWARD J. REED, K.C.B., F.R S., Vice-President I.N.A.

2. "*Danish Steam Ferries and Ice-breaking Steamers.*" By Captain I. C. TUXEN, Director of Naval Construction and Engineering Royal Danish Navy, Member I.N.A.

3. "*On graphic Aid in approximating Hull Weights.*" By Mr. J. JOHNSON (of Gothenburg), Member I.N.A.

IN THE EAST CONFERENCE HALL.

1. "*Crank and other Shafts used in the Mercantile Marine.*" By G. W. MANUEL, Esq., Chief Engineer Superintendent Peninsular and Oriental Steam Navigation Company, Member I.N.A.

2. "*The Formation of Cavities in the Water by Screw Propellers, at high Speeds.*" By SYDNEY BARNABY, Esq., Member I.N.A.

3. "*Experimental Investigation of the Nature of Surface Resistance on Ships and in Pipes*" (*illustrated by Lantern Apparatus and Photograph Transparencies*). By Professor HELE-SHAW, LL.D.

1.30 P.M.—COLD LUNCHEON in the East Garden and Pavilion of the Imperial Institute.

7 P.M.—DINNER of the Institution of Naval Architects at the King's Hall, Holborn Restaurant, Entrance in Newton Street, High Holborn. Evening dress.

Ladies, invited to the Reception at the Admiralty, are informed that they can join the gentlemen who accompany them at the Throne Room, Holborn Restaurant, entrance in Newton Street. This room has been reserved for their use. Light refreshments will be served. The galleries of the King's Hall are also open to ladies who wish to listen to the speeches. The Dinner will be over shortly after 9.30 p.m.

Guests and Members are particularly requested to bring their Cards of Invitation or Coupons with them.

10 P.M.—RECEPTION at the Admiralty by the Right Hon. GEORGE J. GOSCHEN, M.P., First Lord of the Admiralty, and Mrs. GOSCHEN.

THURSDAY, JULY 8.

VISIT TO THE LONDON AND ST. KATHARINE DOCKS, THE ROYAL ALBERT DOCK, THE VICTORIA DOCK, AND THE THAMES IRON WORKS.

10 A.M.—SPECIAL STEAMERS will leave Westminster Stairs, calling at the Charing Cross and Blackfriars landing stages, passing under the Tower Bridge (which will be opened as the steamers pass underneath), and arriving at St. Katharine Wharf at 10.30. The Visitors will land there and walk to the St. Katharine Docks, where the party will be divided into sections. Those comprising each section will be provided with a coloured card instructing them to follow a guide, who will carry a flag of a similar colour. After inspecting the St. Katharine Docks and the London Docks, the party will embark in the London Dock at 12.30. A bugler will sound the assembly, when all the party, whether they have finished their inspection or not, will at once proceed to embark on the steamers at the Dock.

The Steamers will then proceed to the Eastern entrance of the Albert Dock, where they will be locked in, and then steam to one of the Sheds, where Luncheon will be provided at 2 o'clock.

After luncheon the party will divide. Those who desire to proceed to the Thames Iron Works will re-embark in one of the steamers, which will carry them to the Western entrance of the Victoria Dock. They will land there and proceed on foot to the Thames Iron Works, which are close by.

The Thames Iron Works Company will show the party over their Yard, and will invite them to tea.

At 5 p.m. the steamer will be again in attendance at the Thames Iron Works Company's Wharf, and will return to Westminster Bridge, calling on the way at Blackfriars and Charing Cross to land passengers.

Those who desire to see the Cold Meat Store and the Tobacco Warehouse will re-embark after luncheon in the second steamer, and will be conveyed to the Quay adjoining those Departments. When the inspection is completed they will again embark and will return by steamer to Westminster Bridge, calling on the way at Blackfriars and Charing Cross to land passengers.

Printed Guides to the Docks, with plans, and also a description of the objects of interest to be seen at the Thames Iron Works, will be distributed to those who take part in this excursion.

9 P.M.—FESTIVAL CONCERT, followed by a Supper at the Queen's Hall, Langham-place, Regent-street. Evening dress.

The Orchestra at this Concert is composed of 110 Past and Present Members of the Royal College of Music. The Chorus, to the number of 235, is selected exclusively from the famous Leeds Festival Chorus of 1895, which includes contingents from Leeds, Bradford, Huddersfield, Halifax, Dewsbury, and Batley. These are organised, with the express sanction of the Committee of the Leeds Musical Festival, by FRED. R. SPARK, Esq., J.P., the Hon. Secretary of the Committee. The Leeds Festival Chorus has never before sung in London. Madame Albani will be the principal singer. Dr. C. Villiers Stanford will conduct. The Programme is of an International character, pieces being selected from some of the leading composers of France, Germany, Italy, Russia, and Great Britain. Programmes and Books of the Words will be distributed at the Concert.

The Concert will last about 2¼ hours, and Supper will commence immediately afterwards. The Supper will be served in the space under the Dress Circle, also in the Saloon behind, and in the little Queen's Hall upstairs. If necessary, another Saloon on one of the upper floors will also be utilised.

There will be no numbered seats at this Concert. The Coupons will be marked with the name of the part of the House for which they are available. The Foreign Representatives and other Guests and the Reception Committee will, as far as possible, be seated in the stalls.

FRIDAY, JULY 9.

Visit to Portsmouth Dockyard and Southampton Docks.

8.50 A.M.—A special train will leave the Waterloo Station of the London and South Western Railway at 8.50 a.m., arriving at Portsmouth Dockyard at 10.50 a.m. The Dockyard will then be visited, by kind permission of the Lords of the Admiralty.

The Directors of the Union Steamship Company have kindly placed their Screw Steamer *Mexican* (4,661 tons) at the disposal of the Members of the Congress. The *Mexican* will lie at the South Jetty, Portsmouth Dockyard, and ladies and others who do not feel disposed to visit the Dockyard can go on board of her immediately after the arrival of the train, and await the party visiting the Yard.

1.30 P.M.—Luncheon will be served in all the saloons of the *Mexican*.

As the space available in the saloons will not be sufficient to accommodate, at one time, the probable number of guests, luncheon will, if necessary, be served in relays or continuously.

During luncheon, weather permitting, the *Mexican* will proceed for a cruise between the main land and the Isle of Wight, and will afterwards make for Southampton, which will be reached about 4 p.m. After a short inspection of Southampton Docks, a special train will convey the Members from the Docks to Waterloo. The special will start at 4.40 p.m., reaching London at 6.33 p.m.

10 P.M.—Reception by the Hon. T. A. Brassey and Lady Idina Brassey at 24, Park Lane.

SATURDAY, JULY 10.

By gracious permission of Her Majesty the Queen, the Members of the Congress and their Ladies are invited to Windsor Castle on Saturday Afternoon. Special trains will convey the visitors from Waterloo Station at 2.45 p.m. and 2.55 p.m., arriving at Windsor at 3.30 p.m. and 3.40 p.m. respectively. The Specials will leave Windsor to return to London at 6.15 p.m. and 6.25 p.m., stopping at Richmond at 6.45 p.m. and 6.55 p.m. respectively, where they will deposit visitors who intend to dine at the "Star and Garter" Hotel. Brakes and omnibuses will be in attendance at Richmond Station. The Specials will then convey the remaining passengers to Waterloo Station.

Dinner at the "Star and Garter" Hotel, Richmond.

7.30 P.M.—The Members of the Congress and Ladies will dine at the "Star and Garter" Hotel, Richmond Hill. The dinner will be held in the two large Halls in the Hotel. The guests will assemble before dinner in a marquee on the Hotel Terrace. Morning dress.

By kind permission of the Commanding Officer, the Band of the Royal Artillery will be present, and will play in the Gardens during the evening.

As soon as darkness sets in, the Hotel and its Gardens will be illuminated; the Valley of the Thames will be lit up with coloured fire, and a display of fireworks will take place from the

meadows in front of the Hotel. The fireworks and illuminations will be carried out by Messrs. C. T. Brock & Co., of the Crystal Palace, Sydenham.

For the method of reaching Richmond from Windsor, see above.

The best methods of reaching Richmond from London are by the London & South Western Railway Company from Waterloo Station, and by the District Railway Company from the Mansion House, Blackfriars, Charing Cross, Victoria, South Kensington, Gloucester Road, and all intermediate stations.

Trains leave the Waterloo Station five times in the hour for Richmond, accomplishing the journey in from twenty to thirty minutes. By the District Railway the trains run every half hour, and the journey occupies forty-two minutes. Passengers should not take return tickets, as these will not be required by the Special train which will bring them back to London.

At Richmond Station, carriages and other conveyances will be in attendance to meet the trains from London from 6 p.m. onwards, to convey the passengers to the "Star and Garter" Hotel, and, if desired, for a drive in Richmond Park. The same carriages will be in attendance at the "Star and Garter" to convey passengers back to Richmond Station on their return journey.

A special train will convey the visitors back to London by the Metropolitan District Railway. It will start from Richmond Station at about 11.20 p.m. The exact hour will be announced at the dinner. It will stop at Earl's Court, and at all stations between Earl's Court and the Mansion House.

With the Dinner and Fête at Richmond the Meetings of the Congress in London will be brought to a close.

Works open to Members of the Congress during their stay in London, by kind permission of the Proprietors:—

Mr. Peter Brotherhood, Belvedere Road, Westminster Bridge, S.E. The Works will be open on each afternoon from July 5 to 9 inclusive, between the hours of 3 and 4.30 p.m.

Messrs. Humphrys, Tennant & Co., Deptford Pier, S.E. The Works will be open from July 5 to 9 inclusive, between the hours of 11 a.m. and 4 p.m.

Messrs. Maudslay, Sons & Field, Limited, Engine Works at Lambeth, S.E., and Boiler Works at East Greenwich, S.E. Both these Works will be open from July 5 to 11 inclusive.

Messrs. John Penn & Sons, Limited, Greenwich, S.E. The Works will be open on Wednesday, July 7, between the hours of 11 a.m. and 1 p.m., and between 2 and 5 p.m.

The Thames Iron Works will be visited on Thursday, July 8, as explained in the Programme.

Members of the Congress visiting the above Works are requested, in all cases, to produce their badges in proof of membership.

MONDAY, JULY 12.

Excursions to Scotland and Newcastle-on-Tyne for the Foreign Members of the Congress and the Reception Committee.

9.25 A.M.—A Special Express Train will leave the King's Cross Terminus of the Great Northern Railway at 9.25 a.m.

A halt of thirty-five minutes will be allowed at York, where luncheon will be served. The train will reach Glasgow at 7.15 p.m.

The principal Glasgow Hotels will retain a sufficient number of bedrooms for the Visitors, and information regarding the hotels will be supplied to the passengers in the train.

TUESDAY, JULY 13.

Visit to the Fairfield Shipbuilding and Engineering Company, Limited, and to Messrs. William Denny Brothers, Dumbarton.

9.30 A.M.—The steamer *Meg Merrilees* will leave Bridge Wharf, Glasgow, at 9.30 a.m., and will arrive at Fairfield Yard at 10 a.m. The Works will be visited, and the Visitors will be entertained at luncheon by the Firm at 12.15 p.m. The Visitors will leave Fairfield and embark on the steamer at 1.30 p.m., reaching Messrs. Denny's Leven Shipyard at 2.30 p.m. After the Works have been inspected the Visitors will be entertained at tea by the Firm, and will depart by the Caledonian train at 5 p.m., arriving in Glasgow at 5.30 p.m.

Entertainment by the Hon. the Lord Provost and the Corporation of the City of Glasgow.

During the evening of this day the Visitors will be entertained by the Hon. the Lord Provost and the Corporation of the City of Glasgow, at the Municipal Buildings.

WEDNESDAY, JULY 14.

Pleasure Excursion on the River Clyde.

On this day a pleasure cruise will be made on the River Clyde. A special train will leave the Central Station, Glasgow, at 9.20 a.m., arriving at Gourock at 10 a.m. Embark on the steamer *Duchess of Hamilton* at 10.5 a.m. The cruise will be round Arran and Ailsa Craig, going *viâ* the Kyles of Bute and the Sound of Kilbrennon, returning *viâ* the South End of Arran and Fairlie Roads.

Should the weather be unfavourable the route will be through the Kyles of Bute to Inverary, returning *viâ* the South End of Bute.

Either of these tours occupies 7½ hours, at an average of 16 knots speed. If no landing be made at any point of the cruise the steamer will get back to Glasgow at about 6 p.m. Luncheon and afternoon tea will be supplied on board.

THURSDAY, JULY 15.

VISIT TO THE WORKS OF SIR W. G. ARMSTRONG, WHITWORTH & Co., LIMITED, AT NEWCASTLE-ON-TYNE.

On account of the want of Hotel accommodation at Newcastle-on-Tyne, it will be necessary to make an early start from Glasgow, in order that the Visitors may be able to arrive in London the same day.

7.30 A.M.—The Special train will leave the Queen-street Station, Glasgow, at 7.30 a.m., and will reach Newcastle-on-Tyne at 11.10 a.m. The Works of Sir W. G. ARMSTRONG, WHITWORTH & Co., LIMITED, at Elswick, will be visited immediately after arrival.

The Visitors will be entertained at luncheon by the Firm.

4.30 P.M.—The Special train will leave Newcastle-on-Tyne at 4.30 p.m. A halt of 30 minutes will be made at York, where dinner will be served.

The train will arrive at King's Cross Station, London, at 10.25 p.m., and the proceedings of the International Congress of Naval Architects and Marine Engineers will then close.

As will be noticed from a perusal of the above Programme, the Reception Committee have received the most invaluable co-operation outside the Institution in arranging the programme of the Congress.

In the first place, their most humble and grateful thanks are due to Her Majesty the Queen, who, by her most gracious invitation of the members to Windsor Castle, on Saturday, July 10, conferred the utmost distinction upon the Congress. Their most grateful thanks are also due to H.R.H. the Prince of Wales, who, by accepting the office of Honorary President, ensured the success of the Congress; and to H.R.H. the Duke of Saxe-Coburg, and to H.R.H. the Duke of York, who kindly accepted the office of Hon. Vice-Presidents.

In the next place, their warmest thanks are due to Her Majesty's Government, and to the Right Hon. George J. Goschen, M.P., who not only took an active part in the opening and concluding proceedings, but who gave a reception at the Admiralty to the Congress, and gave permission for a visit to be paid to Portsmouth Dockyard.

The Right Hon. the Lord Mayor of London, Alderman Sir J. Faudel-Phillips, and the Hon. Lord Provost Richmond of Glasgow, are also entitled to the heartiest gratitude of the Committee for the hospitable manner in which they entertained the Congress at the Mansion House and at the Glasgow Municipal Buildings respectively.

The Committee desire to express their obligations to Dr. Hubert Parry, Principal of the Royal College of Music, Dr. C. Villiers Stanford, Professor of Music at Cambridge University, and Fred. R. Spark, Esq., Hon. Secretary of the Leeds Festival Committee, for invaluable services in connection with the Festival Concert given at the Queen's Hall.

The Committee are under a deep debt of gratitude to the Joint Committee of the Directors of the London and India Docks who organised a visit to the London and St. Katharine and to the Royal Albert and Victoria Docks; to the Directors of the Thames Iron Works, who arranged a visit to their works and entertained the members; to the Directors of the Union Steamship Company, who placed their screw steamer, the *Mexican*, at the disposal of the Congress for the voyage from Portsmouth to Southampton; to the Hon. Thomas Brassey and Lady Idina Brassey, who gave a reception to the Members at Park-lane; to the Directors of the Fairfield Shipbuilding and Engineering Company, Limited, Messrs. William Denny Brothers, and the Directors of Sir W. G. Armstrong, Whitworth & Co., Limited, each of which firms organised a visit for the foreign representatives of the Congress to their works, and hospitably entertained them.

The Committee also received kind offers from the following well-known firms to organise visits to their works, and to entertain the Members of the Congress, viz. :—Messrs. Palmer's Shipbuilding and Iron Company, Jarrow-on-Tyne; the Clydebank Engineering and Shipbuilding Company, Glasgow; Messrs. Laird Brothers, Birkenhead; and Messrs. Willans & Robinson, Rugby. Lack of time alone prevented the acceptance of these invitations.

Finally, the Committee desire to express their great obligations to the Directors of the London & South-Western, the Great Northern, and the Metropolitan District Railway Companies, who organised the special train services for the transport of the members of the Congress to Portsmouth, Windsor, Richmond, and Glasgow, and for the transport of the Leeds Festival Choir from Yorkshire to London and back.

Since the holding of the Congress the following letters and addresses have been received from various foreign Governments, institutions, and representatives :—

FROM ALL THE FOREIGN REPRESENTATIVES TO THE EDITOR OF "THE TIMES."

THE CONGRESS OF NAVAL ARCHITECTS.

SIR,—Will you kindly permit us through your columns to let our British friends know of our great appreciation of their kindness during the International Congress of Naval Architects and Marine Engineers, which closed yesterday? First of all we must express our gratitude to Her Gracious Majesty the Queen for the gracious reception at Windsor last Saturday, an event that will always live in our memories; and to His Royal Highness the Prince of Wales for opening the Congress and acting as Honorary President. Our grateful and affectionate thanks we also tender to the Earl of Hopetoun, President, and Mr. George Holmes, Secretary, and to the Council and Members of the Institution of Naval Architects for courtesies and attentions without number, and which have made our visit to Great Britain one of the most enjoyable periods of our lives. Your columns, Sir, have already given an account of the series of brilliant receptions, concerts, and excursions which our hosts had provided, and we can assure our kind friends that never before have we been entertained in a manner at once so cordial, so brilliant, and so thoroughly enjoyable. To plan such a series of *fêtes* is a work of some magnitude; to carry them through with absolute perfection in every detail is a task requiring exceptional ability, and on this great success we congratulate our kind hosts most heartily.

In conclusion, permit us to say, Sir, that we believe these international gatherings are productive of great good in making us all know each other better and enabling us to esteem each other's good qualities more thoroughly, and we shall carry home to our respective countries very tender recollections of this splendid exhibition of British hospitality, and of our kind hosts who have made our visit so thoroughly satisfactory and memorable.

To sign all our names would take up too much of your valuable space, as every guest would count it an honour to do so, and we will therefore subscribe ourselves

THE FOREIGN MEMBERS OF THE INTERNATIONAL CONGRESS OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

LONDON, *July* 16.

FROM THE AMERICAN REPRESENTATIVES AT THE CONGRESS.

The American Delegates to the International Congress of Naval Architects and Marine Engineers, profoundly touched by the kindness and hospitality extended to them by the Officers and Members of the Institution of Naval Architects, desire to place on record their high appreciation of the many courtesies they have received, and of the series of truly magnificent entertainments of which they have been guests.

They count themselves specially fortunate in coming to the Mother Country in the year of the Diamond Jubilee of Her Gracious Majesty Queen Victoria, when so much has occurred to make all Anglo-Saxons proud of their race.

They desire specially to thank the Right Hon. the Earl of Hopetoun, G.C.M.G., President, and George Holmes, Esq., Secretary, for their continued and repeated kind attentions, and to congratulate them and the Institution on the wonderfully successful management of one of the greatest gatherings of scientific men of which they are cognisant. And they beg all their kind friends of the Institution to be assured that they will carry home the warmest feelings of affection and gratitude toward them.

(Signed at London, this Sixteenth day of July, 1897.)

C. H. HASWELL,
Late Engineer-in-Chief, U.S.N.

W. H. SHOCK,
Engineer-in-Chief, U.S.N. (retired).

C. H. CRAMP,
President Cramp Shipbuilding Company.

T. H. HYDE,
President Bath Iron Works.

W. IRVING BABCOCK,
Manager Chicago Shipbuilding Company.

D. W. TAYLOR,
Naval Constructor, U.S.N.

W. M. McFARLAND,
Chief Engineer, U.S.N.

C. W. PUSEY, W. W. PUSEY, *Pusey & Jones Shipbuilding Company.*

J. J. WOODWARD,
Naval Constructor, U.S.N.

CHARLES WARD,
Ward Boiler Construction Company.

C. H. WHEELER,
Wheeler Engineering Company.

J. R. ANDREWS,
Hyde Windlass Company.

J. R. OLDHAM,
Agent Lloyd's a Cleveland.

J. MULROONEY,
Proprietor "Marine Review."

J. SWAN, *Naval Architect.*

A. SPERRY, *Naval Architect.*

H. E. ROTTMER, *Naval Architect.*

FROM THE AUSTRO-HUNGARIAN AMBASSADOR.

BELGRAVE SQUARE, *December* 7, 1897.

MY LORD,

His Imperial and Apostolic Majesty, my August Master, has been graciously pleased to command me to convey to you the expression of His Majesty's high appreciation of the assistance you kindly rendered to the Austro-Hungarian delegates during the International Congress of Naval Architects and Engineers held in London.

I am very happy, my Lord, to have the honour to express to you this acknowledgment of my gracious Sovereign, and beg to remain, my Lord, yours very truly,

DEYM,

To the Right Hon. the EARL OF HOPETOUN. *The Austro-Hungarian Ambassador.*

FROM VICE-ADMIRAL CHARLES DUPERRÉ,

OFFICIAL REPRESENTATIVE OF THE FRENCH MINISTRY OF MARINE, AND PRESIDENT OF THE FRENCH RECEPTION COMMITTEE OF 1895.

[*Translation.*]

MINISTRY OF MARINE, *Paris, July* 29, 1897

MY LORD,

It is for me a most agreeable duty to thank you warmly, in the name of the French uests at the International Congress of Naval Architects, for the very cordial welcome which you have given to us. I should be very happy if you would express our feelings to the Members of the Institution who have so perfectly seconded you. We know that the high and inestimable goodwill which Her Majesty the Queen has condescended to show to your guests is, to a large extent, due to the particular esteem in which the President of the Institution of Naval Architects is held by Her Majesty. The never-to-be-forgotten day we passed at Windsor is consequently an additional claim which you have on our grateful remembrance. I am happy, my Lord, to send you the expression of our gratitude and to join to it my most affectionate personal thanks, and at the same time the assurance of my highest consideration.

The Right Hon. the EARL OF HOPETOUN, G.C.M.G. DUPERRÉ.

FROM HIS EXCELLENCY VICE-ADMIRAL TYRTOFF, IMPERIAL RUSSIAN MINISTER OF MARINE, TO CAPTAIN GRIGOROVITCH, NAVAL ATTACHÉ, RUSSIAN EMBASSY, LONDON.

BEG you to thank from my heart the Admiralty and the Institution of Naval Architects for their very kindly and friendly reception and welcome of the Russian Representatives at the late International Congress.

FROM REAR-ADMIRAL STOCKHUYSEN,

OFFICIAL REPRESENTATIVE OF THE ROYAL DUTCH MINISTRY OF MARINE.

DEAR SIR, THE HAGUE, *July* 18.

As I had to leave London early on Sunday, the 11th, the opportunity failed me to pay you a parting visit as it was my intention to do. I beg you to accept and convey to the President of the Institution of Naval Architects, Lord Hopetoun, my heartfelt thanks, and those of the other Dutch guests, for the way we have been received and entertained during our stay in England. We spent days with you never to be forgotten. I am sure that the gathering of Naval Architects in London has added a strong link to the chain that keeps the engineering and shipbuilding world together.

Believe me, Sir, your obedient,

STOCKHUYSEN,

Rear-Admiral R.D.N.

The Secretary of the Institution of Naval Architects.

FROM CAPTAIN J. C. TUXEN,

OFFICIAL REPRESENTATIVE OF THE ROYAL DANISH MINISTRY OF MARINE.

DIRECTEUREN FOR SKIBSBYGNING OG MASKINVÆSEN,
ORLOGSVÆRFTET, COPENHAGEN,

MY LORD, *July* 21, 1897.

On behalf of the Danish Delegates to the Congress of Naval Architects and Marine Engineers, I beg your Lordship to accept and bring to the Committee of the Institution our very best thanks for the exquisite reception and hospitality given to us at the Congress. It is a great honour and pleasure to us to have been present at this very distinguished and successful meeting, and to have enjoyed such special kindness from the English Government, from you and the English Members of the Institution. It will always afford us great delight to think of the ever-memorable days that we spent in England at the Congress, for which we are so much indebted to you.

I remain, MY LORD, yours truly and respectfully,

J. TUXEN.

To the President of the Institution of Naval Architects.

FROM THE GERMAN REPRESENTATIVES AT THE CONGRESS.

[*Translation.*]

THE German participants in the Congress of Naval Architects and Marine Engineers, which was opened in the sixty-year Jubilee of the glorious reign of Her Majesty Queen Victoria by the Hon. President,

H.R.H. the Prince of Wales, and which was assembled under the presidency of the Right Hon. the Earl of Hopetoun, G.C.M.G., desire to express their grateful thanks to the President and Council of the Institution of Naval Architects. They wish to give the liveliest expression to their recognition of the high importance of the Institution, to which, also, His Majesty the German Emperor belongs as an Hon. Member, and to their acknowledgments for the brilliant and friendly welcome which they received in England and Scotland. They are especially sensible of the high honour of the reception by Her Majesty the Queen at Windsor Castle, and they have the best recollection of the many interesting and enjoyable hours prepared for them by the Reception Committee, supported by Her Majesty's Government, and by the hospitality of the Lord Mayor of London, of the Lord Provost and Corporation of the City of Glasgow, of the British Ship and Engine Builders, of the Directors of Steamship Companies, Docks, and Railroads, and of the numerous Members and Friends of the Institution.

Warm thanks are also due to the untiring efforts, which were crowned with the happiest results, of the amiable and esteemed Secretary, Mr. George Holmes.

The German participants in the Congress will never forget the time which they passed in the beautiful land so highly famed for its achievements in ship and marine engine building, and which is distinguished by the energy and intelligence, but also by the hospitality of its inhabitants.

(*Signed*)

HERR BENDEMANN,
Kaiserlicher Kontre-Admiral, Kiel.

,, BEHRENS,
Königlicher Commercienrath, Mitglied des Aeltesten Collegiums der Kaufmannschaft, Berlin.

,, M. BERENDT,
Hamburg (Mem. I.N.A.).

,, HERM. BLOHM,
Hamburg (Mem. I.N.A.).

,, Dr. BÖDIKER,
General-Director der Electricitätswerke, vormals Siemens & Halske, Berlin.

,, D. BREDSDORF,
Director der Flensburger Schiffsbau-Gesellschaft, Flensburg (Mem. I.N.A.).

,, RUD. CRASEMANN,
Hamburg.

,, A. DIETRICH,
Kaiserlicher Wirklicher Geheimer Admiralitäts-rath, Professor, Chef-Constructeur der Kaiserlichen Marine, Berlin (Mem. I.N.A.)

,, ARTHUR DUNCKER,
Director der Nord-Deutschen Versicherungs-Gesellschaft, Hamburg (Assoc. I.N.A.).

HERR GEORGE DYKES,
Lloyd's Surveyor, Hamburg (Mem. I.N.A.).

,, G. EVERS,
Expert des Germanischen Lloyd, Bremen (Mem. I.N.A.)

,, O. FLAMM,
Professor für Schiffbau an der Königlichen Technischen Hochschule, Charlottenburg.

,, CARLOS DE FREITAS,
Hamburg.

,, GÜLICH,
Kaiserlicher Korvetten-Kapitän, Marine Attaché bei der Kaiserlichen Botschaft, London (Assoc. I.N.A.).

,, HAACK,
Civil-Ingenieur, Charlottenburg (Mem. I.N.A.).

,, J. H. HEIDMANN,
Hamburg (Assoc. I.N.A.).

,, GEORG F. HOWALDT,
Königlicher Commercienrath, Director der Howaldtswerke, Kiel (Mem. I.N.A.).

,, HERM. HOWALDT,
Director der Howaldtswerke, Kiel (Mem. I.N.A.).

,, C. ADOLPH JACOBI,
Bremen (Assoc. I.N.A.)

Herr ERNST JACOBI,
Hamburg (Assoc. I.N.A.).

„ von JONQUIERES,
Kaiserlicher Geheimer Ober-Regierungsrath und vortragender Rath im Reichsamt des Innern, Berlin.

„ H. E. JOHNS,
Hamburg (Mem. I.N.A.).

„ KASELOWSKY,
Königlicher Commercienrath, Director der Berliner Maschinenfabriks-Actien-Gesellschaft, vormals L. Schwartzkopf, Berlin.

„ A. KNAFFL,
Dresden (Mem. I.N.A.).

„ KRANOLDT,
Königlicher Wirklicher Geheimer Ober-Regierungsrath, Präsident der Königlichen Eisenbahn-Direction, Berlin.

„ KUHN,
Königlicher Commercienrath, Vorsitzenderdes Vereins Deutscher Ingenieure, Stuttgart.

„ C. FERD. LAEISZ,
Hamburg (Assoc. I.N.A.).

„ LANGNER,
Kaiserlicher Geheimer Admiralitätsrath, Berlin.

„ LEWALD,
aiserlicher Regierungsrath, Berlin.

„ F. ANDREAS MEYER,
Ober-Ingenieur, Hamburg.

„ MIDDENDORF,
Director des Germanischen Lloyd, Berlin (Mem. I.N.A.).

„ Dr. NEUBAUR,
Berlin.

„ Th. PETERS,
Director des Vereins Deutscher Ingenieure, Berlin.

„ ROBERT POHL,
Hamburg (Mem. I.N.A.).

„ Senator Dr. PREDÖHL,
Hamburg.

Herr E. RAUCHFUSS,
Director der Schiffs- und Maschinenbau-Actien Gesellschaft Germania, Kiel (Mem. I.N.A.).

„ G. SACHSENBERG,
Rosslau (Mem. I.N.A.)

„ LUDWIG SANDERS,
Hamburg (Assoc. I.N.A.).

„ OTTO SCHLICK,
Hamburg (Mem. I.N.A.).

„ R. SCHULZ,
Director der Schiffs- und Maschinenbau-Actien-Gesellschaft Germania, Berlin (Mem. I.N.A.).

„ SCHUNKE,
Kaiserlicher Geheimer Regierungsrath, Vorstand des Reichs - Schiffsvermessungs - Amts, Berlin (Mem. I.N.A.).

„ Dr. SIEVEKING,
Präsident des Hanseatischen Oberlandesgerichts, Hamburg.

„ G. SEEBECK,
Geestemünde (Mem. I.N.A.).

„ STAHL,
Director der Stettiner Maschinenbau - Actien-Gesellschaft Vulcan, Stettin.

„ C. TIEDEMANN,
Hamburg (Assoc. I.N.A.).

„ JOHS. TÖNNIES,
Garding.

„ Burgermeister Dr. VERSMANN,
Präsident des Senats, Hamburg.

„ C. O. MAX WALTER,
Schiffbau-Oberingenieur des Norddeutschen Lloyd, Bremen (Mem. I.N.A.).

„ WELLENKAMP,
Kaiserlicher Schiffbaumeister, Kiel.

„ ED. WOERMANN,
Hamburg.

„ CARL ZIESE,
Elbing (Mem. I.N.A.).

„ R. ZIMMERMANN,
Director der Stettiner Maschinenbau - Actien-Gesellschaft Vulcan, Stettin (Mem. I.N.A.).

FROM MONSIEUR L. DE BUSSY,

PRESIDENT OF THE ASSOCIATION TECHNIQUE MARITIME.

[*Translation.*]

MY LORD, PARIS, *August* 3, 1897.

I desire to express to your Lordship, in the name of the Association Technique Maritime, our profound gratitude for the very gracious and brilliant reception given to us by the Institution of Naval Architects, which has the distinguished honour of being presided over by yourself. Permit me, my Lord, to present to you, at the same time, my personal thanks for the very courteous, I would even say most distinguished, welcome with which I have been honoured by your Lordship.

Please accept, my Lord, the expression of my highest consideration.

LOUIS DE BUSSY,
President of the Association Technique Maritime.

The Right Hon. the EARL OF HOPETOUN, G.C.M.G.

FROM THE SOCIETY OF GERMAN ENGINEERS.

[*Translation.*]

43, CHARLOTTENSTRASSE, N.W., *August* 5, 1897.

WE desire to express to the Institution of Naval Architects, and especially to its President, the Earl of Hopetoun, to the Reception Committee, and to its Secretary, Mr. George Holmes, our most grateful thanks for the brilliant arrangements and welcome which they offered to us on the occasion of the International Congress of Naval Architects and Marine Engineers, which can never be forgotten, and will always remain impressed upon our memories; and we hope that it may soon be permitted to us gratefully to return the hospitality which has been shown to us.

(Signed) ERNST KUHN, *President.* TH. PETERS, *Director.*

To the Institution of Naval Architects, 5, Adelphi-terrace, London, W.C.

FROM THE CHAMBER OF COMMERCE OF PARIS.

[*Translation.*]

MONSIEUR LE PRÉSIDENT, PARIS, *August* 7, 1897.

You have done our Society the honour of inviting it to be represented at the Congress held in London last July by the Institution of Naval Architects. Our delegate, M. Hugot, has informed us of the friendly and distinguished welcome which he received from the Members of your honourable Institution. You have, in fact, on the occasion of this Congress, procured for your guests the most interesting studies and the most agreeable pleasures.

The cordiality of this reception cannot fail, we are persuaded, to bind more closely the ties which unite both our countries. We are also most sensible of this new proof of courtesy, and, in the name of the Chamber of Commerce of Paris, I wish to bear witness of our most lively gratitude to yourself and to all the Members of the Institution of Naval Architects. Please to accept, Monsieur le Président, the expression of our most distinguished sentiments.

(Signed) COUVIEUR, *President.*

The President of the Institution of Naval Architects.

FROM THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS, NEW YORK.

To the Earl of Hopetoun, President of the Institution of Naval Architects.

My dear Lord,—At the annual meeting of our Society, it was voted to adopt a minute testifying our appreciation of the courtesies received from your Institution. I have great pleasure in sending you the following Resolutions, which were unanimously passed :—

"Whereas the British Institution of Naval Architects, on the occasion of the Diamond Jubilee of the Queen's reign, invited this Society to join with it and like organisations of other countries in an International Congress of Naval Architects and Marine Engineers, and Whereas the possibilities of hospitality and courtesy were exhausted by the British Institution towards the representatives of this and other like organisations elsewhere, who were its guests :

"Therefore, Resolved that the American Society of Naval Architects and Marine Engineers offer the British Institution this expression of its profound sense of the courtesy extended and of the hospitality lavished ; and, Resolved that a copy hereof be sent by this Society to the British Institution through its President, the Earl of Hopetoun."

I may venture to add my good wishes for the continued success of your Institution and yourself as its President.—Yours sincerely,

CLEMENT A. GRISCOM,
President of the Society of Naval Architects and Marine Engineers.

Dated December 24, 1897.

The following gentlemen from foreign countries and from the United States of America accepted invitations to take part in the Congress, and the great majority of them were present :—

ARGENTINA.

Official Representatives of the Ministry of Marine :
Commander Don O. Betbeder.
Lieut.-Commander Don G. S. Roseti.

Other Representatives.
Lieutenant Don J. Z. Caminos.
Lieutenant Don D. C. Garcia.

AUSTRO-HUNGARY.

Official Representative of the Marine Department, Imperial and Royal Ministry of War :
Commander L. Von Sztranyavszky, Naval Attaché in London.

Other Representative.
Herr J. Kellner, Schiffbau Ober Ingenieur.

BELGIUM.

Official Representative of the Ministry of Railroads, Posts, and Telegraphs :
Monsieur A. Lecointe, Ingénieur en Chef de la Marine.

BRAZIL.

Official Representative of the Ministry of Marine :
Rear-Admiral Dom J. C. Brazil, President of the Brazilian Naval Commission in Europe.

CHILI.

Official Representative of the Ministry of Marine :
Rear-Admiral Don Luis Uribe, Commander-in-Chief and President of the Chilian Naval Commission.

CHINA.

Commander Chen Ngen, Naval Attaché in London.

DENMARK.

Official Representatives of the Ministry of Marine :
Captain J. C. Tuxen, Director of Naval Construction and Engineering.
Captain Rasmussen, Sub-Director of Engineering.

Other Representative.
Captain K. Nielsen.

FRANCE.

Official Representative of the Ministry of Marine :

Vice-Admiral CHARLES DUPERRÉ, Président de la Commission des Travaux.

Official Representative of the French Navy :

Rear-Admiral RICHARD, Naval Attaché in London.

Representatives of the Municipal Council of Paris :

The VICE-PRESIDENT.
The SECRETARY.

Representative of the Chamber of Commerce, Paris :

M. HUGOT, Vice-President.

Representatives of the Société des Ingénieurs Civils de France :

M. J. FLEURY, Ancient Vice-Président.
M. le MARQUIS DE CHASSELOUP-LAUBAT, Trésorier.
M. le COMTE DE DAX, Secrétaire-Administratif.
M. J. J. HEILMANN.
M. HART.

Representatives of l'Association Technique Maritime :

M. L. DE BUSSY, Président.

M. BERRIER-FONTAINE, Vice-Président.
M. E. BERTIN, Vice-Président.
M. le VICOMTE CLAUZEL.
M. P. CARIÉ.
M. DAYMARD, Vice-Président.
M. DRZEWIECKI.
M. DUBAR.
M. DUBOC.
M. DUMINY.
M. FERRAND.
M. FLICHE.
M. GUILLAUME.
M. JANSEN.
M. JULLIEN.
M. LAGANE.
M. LAUBEUF.
M. LEFLAIVE.
M. LOIR.
M. LUCARDIE.
M. MATHELIN.
M. MÜLLER.
M. J. A. NORMAND, Vice-Président.
M. PIAÜD, Secrétaire-Général.
M. REUNER.
M. P. SIGAUDY.
M. TERRÉ.
M. THIRION.
M. VASLIN.
M. VIVET, Secrétaire.
M. VOISIN.
M. WILKINSON.

Representatives of the Société d'Encouragement pour l'Industrie Nationale :

M. E. SAUVAGE. M. PIERRE ARBEL.

Representatives of the Union des Yachts Français :

M. H. MENIER.
M. le COMTE DE FARAMOND DE LAFAJOLE.

Representatives of the Yacht Club de France :

M. le Contre-Amiral COURREJOLLES, Président.
M. le Capitaine de Frégate HEURTEL, Vice-Président.
M. ARMAN DE CAILLAVET, Secrétaire-Général.
M. ANATOLE FRANCE, Membre de l'Académie Française.
M. RÉCOPÉ, Ingénieur des Constructions Navales.
M. DE CALADON.
M. DUMONTPALLIER.
M. BENJAMIN HART.

Representatives of the Société des Forges et Chantiers de la Méditerranée :

M. JOUET PASTRÉ, Président.

Representative of the Chemin de Fer de l'Ouest :

M. MAURICE DEMOULIN, Ingénieur Inspecteur.

Representatives of the Société des Chargeurs Réunis:

M. MIRABAUD, Président. M. DUPRAT, Directeur.

Representative of the Compagnie Générale Transatlantique :

M. PÉRÈIRE, Président. M. GROSCLAUDE.

Representatives of the Usines du Creusot :

M. EUGÈNE SCHNEIDER, Président.
M. CANET. M. MICHEL SCHMIDT.
M. TOUSSAINT. M. DE LAGRANGE.

Representatives of the Société des Ateliers de la Gironde :

M. le COMTE DE BONDY, Président.

Representatives of the Société des Chantiers et Ateliers de la Loire :

M. GUICHARD, Président.
M. CHAUDOYE, Directeur.

Other Representatives.

M. Dugé Bernonville. M. Glasser.
M. Costelnau. M. de Pulligny.
M. Finaz. M. G. Tréboul.

GERMANY.

Official Representatives of the Imperial German Navy:

Rear-Admiral Bendemann.

Representatives of the Imperial German Ministry of Marine:

Herr A. Dietrich, Wirklicher Geheimer Admiralitätsrath, and Constructor-in-Chief of the Imperial German Navy.

Captain Gülich, Imperial German Naval Attaché in London.

Herr G. Langner, Wirklicher Admiralitätsrath.

Representatives of the Imperial German Ministry of the Interior:

Herr Von Jonquières, Geheimer Ober-Regierungsrath.

Herr H. Schunke, Geheimer Regierungsrath.

Herr Lewald, Regierungsrath.

Representative of the Direction of the Royal Prussian State Railways:

Herr Kranold, President.

Representatives of the Verein Deutscher Ingenieure:

Herr Kuhn, Kommerzienrath, President.

Herr Th. Peters, Director.

Other Representatives.

Herr E. Behrens. Herr H. Howaldt.
Herr Doctor Bödiker. Herr C. Adolph Jacobi.
Herr T. Bredsdorf. Herr Kaselowsky.
Herr G. W. Claussen. Herr E. Kuhn.
Herr G. Evers. Herr Jos. L. Meyer.
Herr O. Flamm. Herr Franz Meyer.
Herr R. Haack. Herr L. Middendorf.
Herr G. F. Howaldt. Herr Doctor Neubaur.
Herr E. Rauchfuss. Herr J. Tönnies.
Herr Georg Seebeck. Herr C. O. Max Walter.
Herr G. Sachsenberg. Herr Wellenkamp.
Herr R. Schulz. Herr Carl Ziese.
Herr Director Stahl. Herr R. Zimmermann.

HAMBURG.

Herr Bürgermeister Doctor Versmann, President of the Senate.

Herr M. Berendt. Herr Andreas Meyer.
Herr Hermann Blohm. Herr Robert Pohl.
Herr R. Cresmann. Herr Senator Predoëhl.
Herr C. de Freitas. Herr L. Sanders.
Herr A. Duncker. Herr O. Schlick.
Herr G. Dykes. Herr Doctor Sieveking.
Herr A. Edye. Herr C. Tiedemann.
Herr T. H. Heidmann. Herr Ed. Woermann.
Herr Ernest Jacobi. Herr Wolff.
Herr C. F. Laeisz.

HOLLAND.

Official Representatives of the Ministry of Marine.

Rear-Admiral F. J. Stockhuÿsen, Chief of the Marine Staff.

Mr. C. L. Loder, Director of Shipbuilding.

Mr. J. Beucker-Andreæ, Inspector of Steam Navigation; Hon. Naval Captain.

Other Representatives.

Mr. David Croll. Mr. J. de Bruyn Kops.

ITALY.

Official Representatives of the Royal Italian Ministry of Marine.

Captain Chevalier A. Bianco, Italian Naval Attaché in London.

Colonel Nabor Soliani, Director of Naval Construction.

Commander Gerra. Captain Malfatti.

JAPAN.

Official Representatives of the Imperial Japanese Ministry of Marine:

Captain K. YENDO, Imperial Japanese Naval Attaché in London.

Mr. H. KUROBE, Chief Inspector of Construction.

Mr. Y. TAKAYAMA, Chief Inspector of Construction.

Other Representative.

Mr. S. KONISHI.

NORWAY.

Official Representatives of the Royal Norwegian Ministry of Marine.

Captain C. J. BLOERCH, Royal Norwegian Navy.

Mr. H. S. ARENTZ, Naval Engineer.

Other Representative.

Mr. W. JACOBSEN.

RUSSIA.

Official Representatives of the Imperial Russian Ministry of Marine:

Captain J. GREGOROVITCH, Imperial Naval Attaché in London.

Colonel E. E. GOULAEFF, Chief Naval Constructor.

General BARON HEIMBRUCK, Inspector of Machinery and Member of the Mechanical Department of the Naval Technical Committee.

Other Representatives.

General A. TOROPOFF.

Lieut.-Colonel P. E. TCHERNIGOVSKY.

SPAIN.

Official Representative of the Royal Spanish Ministry of Marine:

Señor DON JOSÉ TORELLÓ, Engineer Inspector 2nd Class of the Royal Spanish Navy.

Other Representative.

General A. A. COMERMA.

SWEDEN.

Official Representative of the Royal Swedish Ministry of Marine:

Count E. H. A. MÖRNER, Royal Corps of Marine Engineers.

Other Representative.

Mr. J. JOHNSON.

UNITED STATES OF AMERICA.

Representatives of the United States Navy Department:

Naval Constructor D. W. TAYLOR.

Chief Engineer W. M. MCFARLAND, U.S. Navy.

The United States Naval Attaché in London:

Lieut. J. C. COLWELL.

Representatives of the American Society of Naval Architects and Marine Engineers:

Mr. J. R. ANDREWS.
Mr. J. ARSENIUS.
Mr. W. IRVING BABCOCK.
Mr. W. W. BATES.
Mr. C. CRAMP, Vice-President.
Mr. J. DE RYCKE.
Mr. C. H. HASWELL.
Mr. R. J. HAWES.
Mr. W. P. HENRY.
Mr. T. H. HYDE.
Mr. W. H. JAQUES.
Mr. D. G. MOORE.
Mr. M. F. MOORE.
Mr. J. MULROONEY.
Mr. J. R. OLDHAM.
Mr. C. W. PUSEY.
Mr. W. W. PUSEY.
Mr. T. G. ROBERTS.
Mr. H. E. ROTTMER.
Mr. W. H. SHOCK.
Mr. J. SWAN.
Mr. W. L. SONNTAG.
Mr. A. SPERRY.
Mr. W. H. C. SWENSEN.
Mr. J. E. THAYER.
Mr. F. VAN VLECK.
Mr. W. H. VARNEY.
Mr. CHARLES WARD.
Mr. C. H. WHEELER.
Mr. J. J. WOODWARD.

PROCEEDINGS IN LONDON.

MEETINGS OF THE INTERNATIONAL CONGRESS

OF

NAVAL ARCHITECTS AND MARINE ENGINEERS.

JULY 6 AND 7, 1897.

THE INTERNATIONAL CONGRESS OF NAVAL ARCHITECTS AND MARINE ENGINEERS.

1897.

THE Summer Meeting of the thirty-eighth Session of the Institution of Naval Architects was held in conjunction with the International Congress of Naval Architects and Marine Engineers, at the Imperial Institute, London, S.W., on July 6 and 7, 1897.

The proceedings commenced with the reception of the Hon. President of the Congress, H.R.H. the Prince of Wales, K.G., and the Hon. Vice-Presidents, H.R.H. the Duke of Saxe-Coburg, K.G., and H.R.H. the Duke of York, K.G., in the vestibule of the Imperial Institute, by the Earl of Hopetoun, President, the Council of the Institution, and the principal representatives of foreign Governments and Institutions at the Congress.

H.R.H. the HON. PRESIDENT of the Congress then proceeded to the Great Hall of the Imperial Institute, where the foreign representatives and the members of the Institution of Naval Architects were already assembled, and took the chair.

H.R.H. the HON. PRESIDENT then delivered the following address of welcome to the members of the Congress.

The HONORARY PRESIDENT of the Congress (H.R.H. the PRINCE OF WALES, K.G., &c.): Ladies and Gentlemen, as Honorary President of this great International Congress, allow me to welcome you all here to-day, not only in my own name, but in the name of the Queen. I am well aware that the progress of the shipbuilding industry is of the greatest importance, and is essential in promoting the commerce of the world and the prosperity of the nation. Let me congratulate you, Gentlemen, on the great strides which have been made during the last sixty years in the shipbuilding profession, and I earnestly hope that during this present Congress the Arts of Naval Architecture and Marine Engineering may continue to be perfected and developed.

H.R.H. the HON. PRESIDENT then called upon the First Lord of the Admiralty, the Right Hon. George J. Goschen, M.P., to speak.

The Right Hon. GEORGE J. GOSCHEN, M.P., First Lord of the Admiralty: Your Royal Highnesses, Ladies and Gentlemen, I have been asked to say a few words, and they will be a very few words, before you settle down to that interesting work which is going to occupy you during

the week. I venture most humbly to add the welcome of Her Majesty's Government to the welcome which has been pronounced by His Royal Highness the Prince of Wales. France and Germany in succession have extended hospitality to the Institution of Naval Architects. We trust that here in England you will spend an equally agreeable time during the coming week. At all events, I can assure you of the heartiest welcome on behalf of this country. I have looked at the intellectual bill of fare to which you are going to sit down almost directly, and which I am sure must try the most severe intellectual digestion. You will occupy yourselves with scientific problems and with the history of shipbuilding and engineering. When I look at the title of the papers which will be read, I feel that a layman would scarcely be able to thread the labyrinth of the problems through which you are to pass. It is enough for us laymen to see the latest development of your science, the monster ironclad, that labyrinth of machinery, through which one finds it difficult to trace one's way. You will settle down to your work, but to what extent, in the course of your labours, you will communicate to each other the latest discoveries of your own minds I am unable myself to say. What you will certainly do is to exchange your views on those broad scientific principles which lie at the bottom of the great science of which you are the representatives. I wish you well through all the conferences which are going to take place; but, as First Lord of the Admiralty I have one hope, which is this, that, while I sympathise with all scientific progress, I trust that you will not light upon any new discoveries which will consign to the category of obsolete ships those which we now possess. In this hope I am sure I have the sympathy of the Ministers of Marine and of some of the distinguished administrators who have honoured us by their presence here to-day. Ladies and Gentlemen, I hope, when you leave these shores, you will carry back with you the memory of pleasant intercourse with each other, and also that you will have found that this gathering of our Institution of Naval Architects has not fallen behind those celebrations in which you have hitherto taken part.

The Honorary President of the Congress (H.R.H. the Prince of Wales, K.G., &c.): I will now call on Lord Hopetoun, the President of the Institution of Naval Architects, to read his address.

The Right Hon. the Earl of Hopetoun, G.C.M.G. (President): May it please your Royal Highness, I desire to tender to your Royal Highness the respectful thanks of this Congress for the gracious address of welcome which you have, on behalf of Her Majesty the Queen, as well as on your own behalf, been pleased to deliver. We are very sensible of the privilege which we enjoy in having your Royal Highness as our Hon. President, and we are intensely grateful that your Royal Highness should, in the midst of the many duties which, at this time especially, devolve upon you, have so graciously found time to be present to-day, and to speak to us, as you have done, in a manner so encouraging and so full of approbation; we wish to assure your Royal Highness that the kindness which you have shown us will not be misplaced, but that the recollection of it will brace our members to fresh efforts in the cause of the great sciences of shipbuilding and marine engineering, twin sciences which have done so much during the last sixty years to promote the growth of good feeling between nations, and which have added so greatly to the comfort and prosperity of the peoples of the world.

We are also highly honoured by the presence of their Royal Highnesses the Duke of Saxe-Coburg-Gotha and the Duke of York. The Society in whose name I speak was founded, amongst other reasons, to enable those who build ships and those whose mission it is to use them to meet together and exchange ideas. It is, therefore, specially gratifying to us to respectfully greet their Royal Highnesses, not only as illustrious members of our Queen's family, but also as distinguished Naval Officers, as practical seamen and experts in the knowledge and usage of ships.

Your Royal Highnesses, Ladies and Gentlemen, we are grateful to the First Lord of the Admiralty for coming here to-day. We thank him both in his own individual capacity, and as representing Her Majesty's Government, for the countenance and support which he has extended to us, and for the cordial welcome which he has, on behalf of himself and his colleagues, offered to our guests.

It is now my pleasing duty to offer, on behalf of the Institution of Naval Architects, a very warm welcome to our foreign guests. Many of those guests have, in the past, extended to us a measure of hospitality in their own countries which we can never forget, and I can assure them that their presence here, affording us, as it does, opportunities of renewing friendships commenced under the happiest of circumstances, is especially agreeable to us.

Wherever, also, representatives of the British race are gathered together, it is always a source of pleasure to them to welcome their kinsmen from the other side of the Atlantic: an identical origin, a common language, and habits of thought in common, are great bonds of union, and the ever-increasing facility of ocean transport cannot but tend to knit more closely together the two great sections of the Anglo-Saxon race.

It is most gratifying to us to count among our guests the representatives of the various great Naval Powers, and we gratefully acknowledge the interest which those Powers have shown in our proceedings, an interest which proves how cosmopolitan is science, and which demonstrates that those who go down to the sea in ships and occupy their business in great waters are brothers all the world over.

We shall endeavour to make the sojourn of these gentlemen in our favoured land as pleasant as possible, and we are not without hope that we shall be able to bring under their notice some objects of interest, the inspection of which may, perhaps, repay them for the trouble and inconvenience to which they have been put in coming over to attend our Congress.

The Institution of Naval Architects, which was founded to promote and improve Marine Architecture and Marine Propulsion, has chosen the present auspicious moment to hold this International Congress, because, the history of these two arts, as we understand them from a modern and commercial point of view, is coincident with and contained within the limits of the long and prosperous reign of Her Majesty the Queen.

We, as a scientific body, are sensible in the highest degree of the privileges and advantages which Her Majesty's wise rule has conferred upon all the liberal arts and sciences, and we are thankful for the freedom of thought, the absence of internal trouble, the long years of national peace which her good government has given us. If, amidst the general rejoicings of the nation, if, along with the acclamations which greet our revered Sovereign at this time, our voices should penetrate to Her Majesty's ears, we would ask Her Majesty to receive our humble congratulations upon the unique event which has just been celebrated, we would respectfully assure our Queen of the intense loyalty and devotion which those of us who are Her Majesty's subjects feel towards Her Throne and Person, and of the respect and admiration which those of our number who owe allegiance to other States entertain towards Her Majesty. It is our earnest and united prayer that Providence, in His wisdom, may spare her to her people for many years to come, and that no great private sorrow, no great anxiety of a public nature, may cloud the autumntide of her life.

I am anxious not to try your patience by overloading my address with figures and statistics, but I trust you will bear with me while I draw a brief comparison between the state of our Mercantile and Military Navies at the time of the Queen's accession and their condition at the present time, and also while I lightly touch upon the most noticeable inventions which have made this development possible.

In the year 1837 the United Kingdom and the Colonies possessed under 3,000,000 tons of shipping. In this year of grace the British Empire possesses nearly 15,000,000. In 1837 the imports and exports combined amounted to £97,000,000. They amount now to £730,000,000. In giving these figures I must remind you that other nations have also made great and rapid strides in the same direction during this period. The fact that our commerce has expanded to such a degree is a proof in itself that our neighbours have increased theirs to a proportionate extent, and we heartily congratulate them upon this fact. The peace-making tendencies of mercantile development are without limit, and every nation benefits by the prosperity of the others. No old world idea has been more thoroughly exploded than has the one that, when a nation is going ahead she is doing so at the expense of her neighbours.

It is a curious fact that almost all the improvements in shipbuilding and ship-propulsion which have enabled the Royal and Mercantile Navies to accomplish their respective tasks have been carried out during the reign of Her Majesty. For two centuries before 1837 the art and science of shipbuilding were in a state of stagnation. It is true that steam had been applied to ships, but the enormous expenditure of fuel, which it entailed, made it unsuitable except for the shortest voyages. Iron, too, had been used in the construction of a few barges and river vessels, but the art of combining the material into ships strong enough for ocean voyages was not generally known.

So recently as the year 1835 the late Dr. Lardner demonstrated, in an apparently convincing manner, the utter impossibility of carrying out steam communication between this country and New York, yet two years later saw the construction of the steamers, the *Sirius* and the *Great Western*, which showed the practicability of Atlantic steam navigation. It may be interesting for us to call to mind that the *Great Western* was a paddle-wheel steamer 212 ft. long, that she occupied sixteen days on her passage to New York, while the *Lucania*, which at present holds the record with her passage of five days, seven hours, twenty-three minutes, is a steel twin-screw vessel 601 ft. long.

It was in the year 1837, also, that the first iron vessel classed at Lloyd's was built. It is also a curious coincidence that, during the first year of the Queen's reign two famous series of experiments with the screw propeller were carried out independently by Mr. Pettit Smith and Captain Ericsson, and resulted in the adoption of this mode of propulsion.

It is unnecessary to follow in detail the successive steps in the development of the screw propeller, but special mention must be made of its application by Mr. Brunel to the steamship *Great Britain*. This vessel contained the germs of many of the features which have since become permanent and was in many respects a most remarkable ship, embodying as she did in her construction some noticeable achievements of Naval Architecture and Marine Engineering. She was launched in the year 1843, and was by far the largest mercantile vessel that had ever been built. She was constructed of iron at a time when this metal was but little used for shipbuilding, and when the proper distribution of the material to obtain adequate strength of hull in large vessels was imperfectly understood. Her dimensions were:—Length, 322 ft.; breadth, 51 ft.; load draught, 16 ft.; and tonnage, 3,500.

With nothing but the experience gained with the *Archimedes* (a small vessel) to guide him, Mr. Brunel took the momentous step of fitting the *Great Britain* with a screw propeller. After various modifications in her engines the *Great Britain* proved herself an absolute success, and made regular voyages between Liverpool and Melbourne right down to our own times.

No sketch of the history of modern shipbuilding would be complete without some reference to the *Great Eastern*, which was commenced in the year 1854, and launched in 1858. She was an iron ship, 680 ft. long, and with eighty-three feet of beam. Her displacement was 22,500 tons. This displacement has never yet been exceeded, though it must be mentioned that Messrs. Harland & Woolf are at present building a steamer, which, though of smaller tonnage than the *Great Eastern*, exceeds her in length by twenty-five feet.

The *Great Eastern*, though built forty years ago, practically landed us in perfection as regards the construction of iron ships. Her longitudinal double bottom and the subdivision of her hull into water-tight compartments are features which have found their way into the most modern practice.

Of all the improvements which have taken place in engines for marine purposes since Her Majesty ascended the throne, the most important and most epoch-making have been the adoption of the surface condenser and the introduction of the continuous expansion of steam in more than one cylinder. These two inventions have rendered possible the subsequent modifications which have so greatly conduced towards economy in fuel consumption; it is to them that we owe that cheap transport by sea which we now enjoy, a boon so necessary to a scattered Empire like ours, and so conducive to the due exchange of the world's commerce.

As Sir John Durston—and here let me pause for one moment to congratulate him upon the well-merited honour which Her Majesty has bestowed upon him—as he and Mr. Milton, two of the most representative engineering authorities in the country, are about to read a paper dealing with these matters, it would hardly be proper for a layman like myself to refer to them in greater detail than I have already done.

Fascinating as is the study of the various improvements which have resulted in the increased development of steam pressures, in the ultimate adoption of water-tube boilers and in the successive steps by which the power of marine engines, in proportion to their weight, has been increased, I will leave to the two distinguished authors whose names I have mentioned the elaboration of this subject.

I cannot, however, resist referring to the latest departure in this long series of achievements, the successful introduction of the steam turbine for purposes of marine propulsion, which was so admirably described by Mr. Parsons in the paper which he presented to us at the Spring Meetings of the Institution.

I have dealt with the growth and development of the Mercantile Navy first, because it is to their mercantile navies that nations must look for the expansion of their commerce and the increase of their prosperity. Whereas war navies, to which I will now refer, exist to protect that commerce and to safeguard the sea-boards of the countries to which they belong.

At the time of the Queen's accession the British Navy was at a somewhat low ebb. You will appreciate this fact when I state that the naval estimates for 1836 only amounted to £2,750,000.

There were at that time some twenty-two paddle-wheel steamers in the Royal Navy, but they were of small dimensions; and, owing to the unsuitability of the paddle system for naval warfare, they were not regarded as a serious element in the floating defence of the country.

But in the year 1837—again this remarkable and never to be forgotten year—the successful application of the screw propeller in the *Archimedes* led to its adoption in Her Majesty's ships, and, in 1844, the first steam frigate, the *Arrogant*, was constructed. From that date up to the year 1859 there was rapidly developed that magnificent fleet of wooden line-of-battle ships and frigates propelled by steam, which culminated in the production of such vessels as the *Howe*, the *Duncan*, the *Mersey*, and the *Galatea*, vessels which for their stately beauty and symmetry of lines have never been surpassed in the history of shipbuilding. But the general adoption of the shell gun in the navies of all European Powers caused grave doubts to be entertained as to their value as fighting ships, and men's minds were exercised to find a type of vessel constructed of a material more suited to the rapidly changing conditions of modern warfare.

So far back as the year 1845 orders were given for the construction of the iron screw frigates *Simoon*, *Megæra*, and *Vulcan*. Before these vessels were finished, experiments were made to test the effect of projectiles on their iron sides. The result of those experiments led the naval authorities to turn these ships over to trooping duties, and to discontinue the use of this material for shipbuilding.

It was not till the year 1859 that the question of constructing sea-going iron ships with protective armour was seriously faced in this country. In that year, the two ships *Warrior* and *Black Prince* were ordered, and they may be regarded as the forerunners of our iron-clad fleet.

From these two ships we can trace the evolution of the modern battleship through its various stages. The belt and battery system, which was brought to such perfection by Sir Edward Reed, was the first serious departure from the type of armoured frigate pure and simple. Sail power was for the first time entirely discarded in the breastwork turret-ships or improved monitors, *Devastation*, *Thunderer*, and *Dreadnought*.

The substitution of mild steel in the place of iron for the hulls of ships, which commenced about 1875, was the next step of importance.

The introduction of the barbette and of the secondary battery, the rapid rise of the quick-firing gun, coupled with the invention of nickel steel and Harveyed armour, have combined to produce the battleship as we see her to-day, with her powerful and well-protected armament, her considerable speed, her great coal endurance, and her undoubted sea-keeping qualities.

Her Majesty, during her long reign, has thus seen her Navy thrice practically reconstructed. She saw her fleet of wooden sailing ships give place to one of wooden steamers. She saw that fleet disappear before a fleet of armoured ships, and now within the last ten years she has witnessed the rise of that magnificent modern Navy, which had its genesis in the programme of Lord George Hamilton, and which the wisdom of successive Boards of Admiralty, coupled with the genius of Sir William White, has added to the defensive force of the country.

It must be a source of the keenest satisfaction to our Queen to feel that, however much the possession of these superlative fleets has contributed towards the dignity of her Crown and the safety of her Empire, she has never (during the last forty years) been compelled to order the guns of her ships to be turned in anger upon any of the civilised nations of the world.

If I have appeared somewhat egotistical in thus dealing entirely with the progress made in our own Navies, my excuse must be that, at the present time, the minds of all of us Britishers are liable to

be bounded by the horizon of our Queen's Empire. I know that our friends from abroad will forgive us if this is so, and that they will be ready to make excuses for us in the special and auspicious circumstances in which we find ourselves placed. But we trust they will believe that, in our soberer moments we, in this country, claim no monopoly in the science and improvement of shipbuilding. We cannot forget that, even in the days of sailing ships, our good friends on the other side of the Channel could give us two stone and a beating in the designs and sailing capabilities of their men-of-war. We cannot forget that they ran us to a dead heat in the production of a steam navy, that they were the pioneers in the building of iron-clad vessels, having been the first to equip floating batteries, and having launched and completed the first sea-going ironclad ever produced; we cannot forget that, they set us the example in the manufacture and use of mild steel for shipbuilding, and, finally, we are constantly reminded that the new water-tube boiler, which we have come to regard as a necessary part of the equipment of our modern war fleet, bears a French name, and is the production of a French firm.

Our American cousins, too, have ever been famed for their inventive genius. They gave us a somewhat rough and practical lesson, early in the century, in the production and handling of powerful sailing frigates. The services of Fulton in the development of steam navigation can never be forgotten. Some of us remember also the magnificent sailing clippers produced in America, which at one time threatened to monopolise the ocean carrying trade of the world.

They possess, likewise, a wonderful ingenuity in adapting types to special circumstances. Their light-draught river steamers, those magnificent floating palaces which can almost traverse the dry land, provided the morning dew be heavy, and their whale-back boats used for the grain trade on the great Lakes, are examples of that ingenuity.

The art of shipbuilding owes something to each of the great maritime Powers of the world. As a salient instance of this I may remind you of the heavy debt of gratitude which the whole shipbuilding profession owes to the metallurgical discoveries of Henry Bessemer and of the brothers Siemens. Other nations, too, have done valuable work by perfecting the details of inventions adopted from neighbouring countries, and by demonstrating in a practical manner the utility and desirability of many of the improvements, the use of which has now become general; and if I turn to the scientific work of the Institution of Naval Architects, I shall, I know, command universal support when I acknowledge how greatly we have been helped in doing that work by our neighbours and good friends on all sides.

It is not necessary for me to weary your Royal Highness by summarising the valuable work which this cosmopolitan Institution has done and is doing. Amongst our most active members we count men who represent the aristocracy of brains in that particular science with which we are associated, and your Royal Highness's kindness to us to-day is a proof in itself that you take us seriously.

We thank you again for your presence, and we would ask that, before leaving this Hall your Royal Highness will be pleased, as our Hon. President, to sign and permit us to send the following short telegram of congratulation to Her Majesty the Queen :—

"The International Congress of Naval Architects and Marine Engineers, at present in session at the Imperial Institute, offer their dutiful congratulations to your Majesty at this auspicious time, and they earnestly pray for your Majesty's happiness and welfare."

His Royal Highness the Prince of Wales having appended his signature to the telegram, then left the hall, accompanied by their Royal Highnesses the Duke of Saxe-Coburg and the Duke of York, and by the Right Hon. George J. Goschen, M.P., First Lord of the Admiralty.

The meeting then divided. Those who wished to hear the papers on Shipbuilding and Naval Architecture remained in the Great Hall, while those who wished to be present at the reading of papers on Marine Engineering adjourned to the East Conference Hall.

The following gracious reply was received shortly afterwards by H.R.H. the Hon. President, from Her Majesty the Queen :—

"My sincere thanks for the good wishes you have sent me.—VICTORIA, R.I."

HARDENED PLATES AND BROKEN PROJECTILES.

By Mons. L. E. Bertin, Honorary Member.

Read at the International Congress of Naval Architects and Marine Engineers, at the Imperial Institute, July 6, 1897; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

If I seek to detain your attention in a subject hitherto reserved for specialists, I beg of you not to be too severe. I wished above all things to respond to the flattering desire which was expressed to me that one of your oldest French members should take an active part in a Congress to which you have invited the maritime world. I thus accomplish a duty of seniority for the twenty-five years that have elapsed since I have had the honour of belonging to you. If my paper appears to you destitute in technical novelties, believe, at least, that it is rich in thanks for the reception which my works have always found in your volumes, as also for the reception which you are to-day giving to all of us in your hospitable city.

I have often enough attacked here the inexhaustible subject of pitching and rolling. I have wished that the courteous lance broken last year with Mr. R. E. Froude should be the last. Nevertheless, I do not absolutely desert the lists of the tournament, since I am going to speak about armour.

The simple plate of steel, the history of which Mons. Barba was able to relate to you with authority six years ago, has been relegated since then, together with the compound plate, to the museum of ancient powers dethroned. The Harveyed plate enjoys the favour of to-day; it is it which defies the projectile by breaking it. The memoir of Mr. Charles Ellis, which is still full of actuality, invites us to an easy sequel. I will speak afresh of Harveyed plates, while avoiding the burning ground of personal interests, and perhaps in them I will find the subject of a discussion which can bring about those "friendly rivalries" to which Sir William White invited us in 1894.

I.

In 1893 I visited the works at Bethlehem with Mons. Leflaive exactly at the moment when the first industrial application for Harveying plates was installed. We had been invited by the Navy Department to assist at the experiments in the new polygon of Indianhead, and we saw the projectiles fly into splinters on contact with the

hardened surface of the plate. At Indianhead, as well as at Bethlehem, we had heard, in the midst of nearly unanimous praise on the subject of the inventions of Mr. Harvey, doubts formulated, such as those which Captain Orde Brown expressed at the Institution in 1894. As I remained, in consequence, a little perplexed, I received, with all the joy of an aspirant to the faith, the memoir of Mr. Charles Ellis, which catalogued, classed, and discussed the effects of 108 projectiles fired against thirty Harveyed plates, and, on my side, I made an analysis of the results. I will present to you as the commencement of the subject the results of a very summary analysis of Mr. Ellis's tables, which is contained in a study of the American Navy, of which I have offered a copy to the Institution. Mr. Ellis took care to calculate, for each of these 108 shots, the corresponding penetration in soft iron as indicated by two formulæ, namely, that of Gâvres and that of Jacob De Marre, and he compared the results with the thickness of the plate; he indicated the ratio of the calculated to the observed penetration. Amongst the 108 shots, all of which I examined without prejudice, I have selected 68 for which the value of the penetration could, as it appeared to me, be exactly figured out. Of these 68 shots, some were found, the penetration of which exceeded the thickness of the plate; for these I have added to the thickness of the plate the tenth part of the thickness of the backing which was penetrated. This correction is, doubtless, not exact; but, in any case, it is sufficiently near the mark, so that, the error committed cannot have the smallest practical importance. That being done, I calculated the ratio K of the penetration in soft iron ϵ_1, as given by the Gâvres formula, to the actual penetration observed e, for all the 68 shots indifferently, as well as for the partial penetrations to which empirical formulæ, like that of Gâvres, do not apply in principle, as this latter only applies to total penetration.

The 68 shots considered give, as the value of K, a mean equal to 2·6, in virtue of which the Harveying would seem to increase the resisting power of steel plates in a proportion above 50 per cent. In effect, a Harveyed plate of 30 cm. thickness, for example, would be equivalent to $30 \times 2{\cdot}6 = 78$ cm. of soft iron, while a plate of ordinary steel, of 45 cm., is considered as being equivalent to only 60 cm. of soft iron.

Pushing the analysis a little further, I divided the 68 shots into two groups, namely, 19 shots in which the projectile remained entire, and 49 in which it was broken. I endeavoured thus to find out the part played by the rupture of the projectiles in increasing the resistance of the Harveyed plates. The 19 shots in which the projectile remained entire all gave complete perforation; the empirical formulæ are, consequently, applicable to them. These 19 shots give a mean value of only 1·19 for K; even this value of K is too great to express the increase of the resistance, for several of the projectiles traversed the target completely, and still preserved a certain velocity. The 49 shots in which the projectile was broken are more favourable to the Harveying

process; 13 shots produced complete perforation, and gave a mean value of 1·38. The remaining 36, which only produced a partial penetration of the plate, give a mean value of 3·50 for K, with individual values reaching as high as 10, but the formula is not applicable in their case.

The three values of K, 1·19, 1·38, 3·50, taking into account the small amount of interest which attaches to the latter figure, still leave the superiority of the Harveyed plates somewhat undecided, since good plates of homogeneous steel, such as those of Le Creusot, when compared with soft iron easily attain values of K equals 1·30. The preceding results appeared to me to deserve a deeper study of the question. I have taken care in selecting them from 1894 to treat them as provisional, the practice of Harveying having been at that time only at its commencement. We shall see later on, that the progress realised since 1894 in the manufacture of plates has justified these prudent reserves.

II.

In the following study I have, in order to express the penetration of non-Harveyed steel plates, taken the formula—

$$\epsilon = \left(\frac{1}{1530^2}\,\frac{p\,v^2}{a^{1.5}}\right)^{\frac{1}{1.4}} \qquad (1)$$

where—

ϵ = the thickness of the plate strictly perforated in decimetres.
p = the weight of the projectile in kilos.
v = the velocity of the projectile in metres.
a = the diameter of the projectile in decimetres.

This is Jacob de Marre's formula for the penetration of co-temporaneous steel plates made by M. Barba at Le Creusot. The very regular and definite quality of the metal corresponds very nearly with that of actual plates before they have undergone the Harveying process. The use of this formula is then appropriate to the study of the increase in resisting power due to Harveying.

If we call e the thickness of plates to be compared with the steel plates of Le Creusot, we can express their resistance to strict perforation by the formula—

$$e = \frac{1}{R}\,\epsilon$$

$$e = \frac{1}{R}\left(\frac{1}{1530^2}\,\frac{p\,v^2}{a^{1.5}}\right)^{\frac{1}{1.4}} \qquad (2)$$

The quality of a metal to be compared with Le Creusot steel is very often expressed, not by the ratio R between the thickness of plates corresponding to strict perforation, for a given projectile and a given velocity, but by the ratio ρ of the velocities necessary with the same projectile, in order to perforate the same thickness of the different plates.

$$v = \rho \left(1530^2 \frac{a^{1.5}}{p} e^{1.1} \right)^{\frac{1}{2}} \qquad (3)$$

When the resistance of the metal goes on increasing, the law of the decrease of thickness e is more rapid than the law of the increase of velocities v. The following table gives the corresponding values of R and ρ within the limits which the actual perfection of manufacture of armour permits us to consider in practice. We may admit, as a rule of thumb, that the increases of R are 1·5 times those of ρ.

ρ	$R = \rho^{1.7}$	$\frac{1}{R}$
1·05	1·072	0·933
1·10	1·146	0·873
1·15	1·221	0·819
1·20	1·298	0·771
1·25	1·375	0·727
1·30	1·455	0·687
1·35	1·535	0·651
1·40	1·617	0·618
1·45	1·700	0·588
1·50	1·784	0·560

If the formula (1) be written in the form

$$p\, v^2 = 1530^2\, a^{1.5}\, e^{1.1} \quad (1A),$$

it is better adapted to making the distinction between the work due to the perforation of the plate and that due to the rupture of the projectile.

The formula 1A applies to projectiles which remain entire. Let us suppose that, owing to the hardening of the surface, the projectiles break while the resistance of the plate to a rigid projectile is not sensibly increased.

Let A be the momentum absorbed by the rupture of the projectile and e the thickness of the plate corresponding to strict perforation by the broken projectile, we get—

$$p\, v^2 = 1530^2\, a^{1.5}\, e^{1.1} + A,$$

whence we obtain—

$$e = \left(\frac{1}{1530^2} \frac{p\, v^2 - A}{a^{1.5}} \right)^{\frac{1}{1.1}} \qquad (4)$$

Combining the formulæ (2) and (4), we find the following relations between the co-efficients R and A:—

$$\frac{1}{R} = \left(1 - \frac{A}{p\,v^2}\right)^{\frac{1}{14}} \qquad (5)$$

$$\frac{A}{p\,v^2} = 1 - \left(\frac{1}{R}\right)^{14} \qquad (5A)$$

It is, moreover, self-evident that, when comparing hardened and non-hardened plates, or, rather, blows from broken and not broken projectiles, the co-efficient A calculated by formula (4) does not represent the work of fracture of the projectiles alone. It should be understood that the variable co-efficients R and A are, in reality, functions of all the conditions of the experiment. One cannot make use of simple empirical formulæ like the preceding without this reserve.

III.

The 108 shots, the effects of which Mr. Ellis studied and classified in his table, should, from the point of view of the present study, be divided into two series according as the projectile remains intact or has been broken. In each of the two series we must afterwards distinguish three cases—that in which the target has been completely traversed; that in which the whole of the plate has been traversed, but not the target; and, lastly, that in which the plate has only been partially penetrated.

The shots may thus be divided into six groups, as is shown in Table I. in which each of them is specified by the number of its order in Mr. Ellis's table. In this table the calculated values of ϵ and the value of the observed penetration e given by Mr. Ellis have been inscribed, while account has been taken of the thickness of the backing penetrated, as has been said above. Also the value of R has been entered, and that of $\frac{A}{p\,v^2}$ for all the shots for which the value of e is known.

First Series.—Unbroken Projectiles (24 Shots).

Group I.—This group comprises 7 shots, in which the projectile, after having completely penetrated the target, was not always recovered. The value of e is unknown; we can but compare ϵ with the thickness E of the plate alone; the thickness of the backing and of the skin plating not being given. The mean value of the ratio of ϵ to E is 1·42, which shows that the sides of ships run great risk of being penetrated when the ratio of ϵ to E exceeds 1·40. For the shots numbered 8, 9, and 108, the ratio of ϵ to E is less than 1·30; the penetration realised in these conditions, regard being had to the resistance of the plates in the case of the majority of the other shots, proves that in 1894 the efficacy of Harveying was still subject to great irregularities.

Group II.—This group comprises 16 shots, in which the plate was completely penetrated, and the backing partially so. We thus have values for e, R, and $\frac{A}{pv^2}$.

The results of all the shots agree with each other in a remarkable manner. The ratio R remains between 0·93 and 1·08; its mean value is 1. The ratio of A to $p\,v^2$, sometimes positive, sometimes negative, never exceeds 0·10 in absolute value, and its mean value is zero. The conclusion is that the resistance of Harveyed plates is exactly the same as that of those which are non-Harveyed when the projectile is not ruptured.

Group III.—One single shot, No. 65, having given an imperfect penetration of the plate, the ratio of R to the observed penetration attained 1·14. We have here to deal with an abnormal projectile, which, as is pointed out in Mr. Ellis's table, was considerably set up; without this setting up, we should have had complete penetration of the plate, as in the case of projectiles 63, 64, and 66 of Group II., which were fired against the same plate. The conclusion deduced from the shots of Group II. need not therefore be modified.

Second Series.—Broken Projectiles (69 Shots).

Group IV.—This group also comprises seven shots, in which the projectile, while being broken up, completely penetrated the target in such a manner that the splinters were not always found. Contrary to appearances, the results of these seven shots are not particularly unfavourable to Harveying; we see, in fact, in Table II. that the mean value of the ratio of ϵ to the thickness of the plates E was 1·6, varying between 1·4 and 1·8; the plates therefore were in general much too weak for the projectiles. The only conclusion we can come to is that we are not certain of stopping the projectile in the wall when the ratio of ϵ to E exceeds 1·4 for the plate alone, even when the plate has been sufficiently well hardened to break the projectile.

Group V.—This group, which is the most important of all, comprises 29 shots which penetrated the plate, but did not completely penetrate the target. It is divided into two parts in Table II.

In the case of 17 shots, the penetration is such as to permit us to calculate e. The ratio R, varying between 0·98 and 1·66, presents considerable irregularity, which is explained by the great difference in the momentum absorbed by the projectile, according as it has been broken into small splinters or simply cracked. The same variations are found again in the value of $\frac{A}{pv^2}$, which is negative for the two shots 7 and 69, and almost zero for the two shots 58 and 67. If we turn to Mr. Ellis's table, we see that the projectile 7 was broken up a little, and the projectile 58 was cracked into three pieces only. Four shots out of 17 give values of R superior to 1·4, and one

gives an abnormal value which reaches 1·76; the mean values are 1·30 for R and 0·27 for $\frac{A}{p v^2}$.

In the case of 12 shots, we only know that the plate has been penetrated, without knowing the depth of the penetration into the backing. In Table II., the thickness of the plate, E, has been substituted for the unknown value of e. Consequently the calculated values of R are too large, as also are those of $\frac{A}{p v^2}$, which is the opposite result to that shown by the first 17 shots, in the case of which the correction made for the backing is probably a little exaggerated. It should result from this, and in fact does result, that the ratio R is notably larger in the case of the second part of Group V.; it oscillates between 1·14 and 1·80, and is, on the average, 1·54. The last figure would justify the efficacy attributed to Harveying from the outset, when this operation was represented as increasing the resisting power of armour by 50 per cent.

For these 29 shots the mean value of R is 1·4, and that of $\frac{A}{p v^2}$ is 0·37. These figures when compared with those of Group II., namely 1 and zero, give a good indication of the effect which Harveying produces in breaking up the projectiles.

Group VI.—This group comprises 33 shots which only partially penetrated the plate, often only to the extent of one-half, and sometimes to only one-quarter, of its thickness. As the work of resistance of the plates is produced to a much greater extent during the perforation of the front layers than during that of the back layers, formula 1 does not apply to the penetration of the shots in Group VI. If, nevertheless, we consider the values of ϵ, those of E, and those of $\frac{A}{p v^2}$ which have been inserted in Table II., we see there especially an indication of the difference of resisting work corresponding to the successive stages of the penetration. The values of R were very variable, much more so than they would have been with ordinary plates; they are comprised between 1·8 for shot No. 68 and 7·93 for shot No. 72. The value of $\frac{A}{p v^2}$ exceeds 0·9 for shots Nos. 44, 72, and 103; the mean values are 2·8 for R and 0·7 for $\frac{A}{p v^2}$. It appears to be very certain that projectiles, which are too weak to seriously penetrate armour, produce much smaller indentations when the latter has been Harveyed.

A special column for the shots of Group VI. in Table I. gives the ratio of the calculated penetration ϵ to the thickness E of the plate. We remark in this column that, in the case of nineteen shots the ratio of ϵ to E is inferior to 1·10, and that, in the case of six shots, it is even inferior to 1. Thus, for rather more than half the shots, the projectile, which did not succeed in perforating a Harveyed plate, would have been equally prevented from perforating a very good non-Harveyed plate, and even, in six

cases, an ordinary steel plate. On the other hand, out of fourteen shots which would have certainly perforated an ordinary plate, eight are found with which the ratio of ε to E exceeds 1·30, and in the case of three of these it even exceeds 1·60.

Series of Non-Classified Shots.

The six preceding groups comprise altogether 93 shots. In addition to these there remain—

Group VII.—Seven shots for which the penetration is indicated as being slight. The projectile was always broken.

Group VIII.—Eight shots, the results of which were not exactly defined. In the case of projectile No. 10, the projectile was set up and cracked; for shot No. 102 the state of the projectile was not indicated; for the other six shots the projectile was broken.

The preceding rather minute examination, and the classification of shots which serves as its foundation, do not lead to conclusions sensibly different from those at which I arrived in 1894, after a much more summary analysis. They, however, facilitate and render more precise the comparison of the results, collected and discussed by Mr. Ellis, with those of the more recent experiments which we are about to examine.

IV.

In undertaking this paper I could have wished to treat the results obtained previously to 1894, and already studied in so masterly a way by a specialist such as Mr. Ellis, only by way of preface. Unfortunately the new elements which I have been able to gather together are neither numerous enough nor varied enough to permit of this; they can only furnish a sequel to the preceding chapter, showing, as they do, the progress realised in the course of the last three years.

I have here only to consider the results of 39 shots fired with projectiles of hard steel, without caps, against 23 Harveyed plates coming from different sources. These results, given in Table II., have been classed in groups corresponding to those of Table I., and under similar headings, in such a manner as to render the comparisons easy.

The first series is wanting almost completely in Table II. This is the result, not of the small number of new experiments, but rather of the increased hardness of surface obtained by the Harvey process. One single projectile only, No. 39, was not broken, while before 1894 nearly one in four remained entire after firing.

Moreover, in the second series the great majority of the shots belong to a single group, the penetration of the plate having nearly always been incomplete. If then, the

conditions of firing were determined beforehand, with the object of obtaining complete perforation, as is usually the case, the resistance of the plates generally surpassed anticipations.

GROUP IA. is totally absent.

GROUP IIA. comprises one single shot, which perforated the plate with partial penetration of the backing. The results are

$$R = 1{\cdot}40 \text{ and } \frac{A}{p v^2} = 0{\cdot}38,$$

figures which are plausible enough, but, nevertheless, a trifle small when compared with those found for the other groups.

GROUPS IIIA. and IVA. are missing.

GROUP VA. contains 6 shots, where the projectile, while breaking up, has perforated the plate and a portion of the backing. For four shots the results agree very well, and give, on the average—

$$R = 1{\cdot}39 \text{ and } \frac{A}{p v^2} = 0{\cdot}38.$$

The two abnormal blows are No. 111, which is very unfavourable to the plate, and gives—

$$R = 0{\cdot}99 \text{ and } \frac{A}{p v^2} = -0{\cdot}013 ;$$

and shot No. 115, which is very unfavourable to the projectile, and gives—

$$R = 1{\cdot}74 \text{ and } \frac{A}{p v^2} = 0{\cdot}55.$$

The general averages for the six blows are—

$$R = 1{\cdot}38 \text{ and } \frac{A}{p v^2} = 0{\cdot}34.$$

These results, when compared with those of Group V. in Table I., would seem to indicate a diminution in the resistance of the plates since 1894; but we must not lose sight of the complete absence of Group IIIA., which has caused all the blows unfavourable to the plate to be brought into Group IV.

GROUP VIA. contains 32 shots—that is to say, nearly the whole of the results of the new experiments. The calculations made in the same way, as previously, indicate that R has varied from 1·07 to 4·66, and has had the average value of 2·64, and that $\frac{A}{p v^2}$ has varied from 0·093 to 0·884, and has had the mean value of 0·68; thus, as has been already said, the value of these ratios varies very much with the depth of penetration in the plate, and consequently presents but little interest. The comparison of the total thickness of the plates E and the thickness ϵ, which would have been completely perforated without Harveying, is much more important. We see that, in the column of Table II. which gives the ratio of ϵ to E, this ratio is greater than 1·30 for

15 of the 32 shots of Groups VIA. which attained complete penetration—and that it is even superior to 1·5 for 5 of these 15 shots. These 15 shots—and, above all, the 5 best of them—would have attained complete perforation before 1894, according to the average results of the best calculated part of Group V., Table I. This is the principal deduction to be drawn from the tables on the subject of the progress realised in the manufacture of Harveyed plates since the year 1894.

To sum up, we have the right to exact nowadays a value of R = 1·40 for complete penetration of Harveyed plates, and we may hope to obtain 1·50, the projectile being always supposed to be broken.

As a sequel to Table II. I have inserted in Table III. the results obtained since 1894 from firing twenty-two projectiles against non-Harveyed plates of recent manufacture. The metal employed is no longer the ancient classic steel of Le Creusot, each manufactory has its own, which is designated by the term "special steel," with remarks of the maker.

In Table III. nearly all the projectiles have remained entire, just as we should have expected.

There are two principal groups, IIB. and IIIB., which in reality form a single group of eighteen shots, because the penetration, when it was not quite complete, was very near being so. The results of these eighteen blows, which agree very well with one another, give the mean values of

$$R = 0{\cdot}95 \text{ and } \frac{A}{pv^2} = -0{\cdot}08.$$

Only four shots forming Group VB. caused the projectile to break; the value of R then rose to 1·07, and that of $\frac{A}{pv^2}$ to + 0·07. These results, when compared with those which precede them, the perforation having been complete in all cases, show that the breakage of the projectile on a non-Harveyed plate absorbs 15 per cent. of its momentum. The rupture of the projectile consequently appears to be less efficacious than when Harveyed plates are employed, no doubt because it is less complete.

The total results are not very encouraging for the manufacture of non-Harveyed plates. Nevertheless, in consequence of the least unfavourable results, like those of shots 163 and 167, some manufacturers hope to obtain the value R = 1·10 under industrial conditions without having recourse to Harveying.

V.

After this dry enunciation of experimental data, of which the only exact figures are the momenta of the projectiles which are absorbed in the blow, it is desirable to distinguish, even without defining them numerically, the principal elements of resisting

power of the plates. While distinguishing the work of the shield as absorbing the blow, and that of the projectile as an instrument of penetration, we can succeed in foreseeing the means of perfecting both of them.

The momentum retained by the projectile after the blow, or by its splinters which rebound backwards, is of little importance. The idea of so arranging the shield as to permit of the plates being displaced backwards and allowed to return to their original position has often been thought of, but experiments in this direction have only given insignificant results.

The elastic deformations of the plates may attain a considerable value; we have the proof of this, in the case where the plate is broken, by the play of elasticity along the cracks, by virtue of which the diameter of the hole is less than the diameter of the projectile. We know, moreover, that the metals which make the best plates are metals having a high elastic limit.

By far the largest portion of the work absorbed by the plate is expended in producing permanent deformations, some of which are general, and others local.

The general permanent deformations are composed of flexures, or bendings, in which the walls themselves participate, and which may produce inlets for water to the ship without the wall having been penetrated, and molecular displacements which, in general, are not revealed by any exterior sign on thick plates. The interior molecular work of the plates would, without doubt, not have been suspected, if it had not been clearly manifested by the curves of Commandant Hartmann on the backs of thin and very homogeneous plates.* Plate I. gives a remarkable example in which the two systems of logarithmic spirals, having the axes of the projectile as their pole, are drawn with geometrical precision. Further on we shall see an analogous effect produced on the projectile. The operation of Harveying, insomuch as it alters the homogeneity of the plates, is probably unfavourable to the molecular work about which we are writing.

The permanent local deformations are produced by the passage of the projectile, the sharp ogival head of which penetrates nowadays somewhat after the manner of a prow, by forcing the metal to flow on all sides according to the law of the least resistance. On plates having a soft and ductile surface, a portion of this flow takes place on the front face, which is raised up in the shape of a burr, terminated by the well-known thin sheets which are seen in Fig. 2, Plate II. On Harveyed plates the inflexible surface does not lend itself to any permanent deformation; it can only fly into fragments around the point of impact, as is shown in Fig. 3, Plate II. This

* On the subject of these curves see the "Comptes-rendus de l'Académie des Sciences de Paris," March 5, 1894.

stiffness of the Harveyed surface opposing the flow of the underlying layers should increase the resistance to penetration.

Even in the body of the plate the metal can only be pushed back laterally if the entire plate breaks up, thus lending itself to the elastic deformations before mentioned. The resistance to the formation of cracks causes the whole plate, and even the neighbouring plates, to work; the metal thus strongly framed in is in better condition to resist rupture than the projectile, which latter does not benefit by any framing in until it has penetrated the plate.

Finally the greater part, and very often the whole, of the metal pushed back escapes by the rear face of the plate. The bulb, which is raised at first, is broken by flexure from the centre to the circumference, and thus forms a funnel at the exit, the diameter of which is generally greater than that of the projectile. We thus find something which has somewhat of the appearance of the countersunk holes obtained by punching a plate.

The manner in which the resistance of the plate diminishes in proportion as the projectile advances, and the differences which thus result between the different portions of the work of resistance, corresponding to the different stages of the penetration, depend upon all the mechanical properties of the metal, on its laminated or non-laminated molecular structure, or the more or less perfect union between the different layers, &c. We have only to consider here the *rôle* played by the exterior hardened face produced by Harveying.

In the partial penetrations of Harveyed plates the value of R, which is very great for simple impressions, diminishes rapidly when *e* increases.

If we take for abscissæ the values of $\frac{\epsilon}{E}$ and the corresponding values of R as ordinates, we find that the ratio of Δ R (the variations of R) to $\Delta \frac{\epsilon}{E}$ the variations of $\frac{\epsilon}{E}$) is $-5{\cdot}6$ for plate 39, shots 126 and 127, and $-5{\cdot}2$ for plate 42, shots 130 and 131; while it is $-0{\cdot}4$ only for plate 35, shots 115, 131, and 132. Thus we do not see the appearance of any general law applicable to all plates.

For the much more important study of the values of R which correspond with complete penetration, if we take the thickness of the plates E as abscissæ and the values of R as ordinates, the general tendency of a law can be perceived in the midst of irregularities depending on various causes. The value of R would attain a maximum greater than 1·40, or even 1·50, for values of E rising from 25 to 30 cm.; it would afterwards diminish, and would descend from 1·25 for values of E equal to 40 cm. The conclusions in subdivision IV. in favour of Harveyed plates, which assign to them a value of R equal to 1·40, would not, therefore, be general; a Harveyed plate 25 cm. in thickness

would be fully equivalent to a non-Harveyed plate of 35 cm.; but a Harveyed plate of 40 cm. in thickness would only be equivalent to a non-Harveyed plate of 50 cm. This diminution of R, as E increases, is *à priori* probable enough. We must, however, make certain reservations on the preceding figures, because the thicknesses hitherto tested stop at 37 cm.; but the projectile fired against the latter plate appears to have been wanting in hardness.

Amongst the particular values of R, which depart the most from the general law, the most remarkable are those obtained in plate 35. This plate, which was made of a special metal, had nothing peculiar in regard to its Harveying.

In the firing experiments which we have considered, the projectiles were generally of a type created about fifteen years ago by M. Jacob Holtzer d'Unieux, which, since that time, have only undergone slight improvements. As Harveyed plates draw all their advantages from their property of breaking these projectiles, it is necessary to find for use against them projectiles which offer a better resistance to rupture.

The sudden stopping against an inflexible surface produces a violent compression, even of the body of the projectile, which may lead to its rupture. Fig. 4, Plate III., represents a shell which was thus visibly broken by excess of compression. The lines of rupture follow the curves of Commandant Hartmann, namely, two spiral networks, one on the right and one on the left, and making the same angle with the generatrices. In order to prevent this kind of rupture we must make use of a very tenacious metal, and, above all, give a sufficient thickness to the sides of the shell.

The causes of the rupture of the ogival head, and the means of preventing it, require a more delicate examination. Let us consider the case of the rupture of a projectile of good quality, such as the one represented in Fig. 5, Plate III., which perforated plate No. 35. The point of the head was flattened by the blow, and took the form of a punch, which latter commenced the penetration; the ogival head afterwards entered the metal like a wedge. In proportion as the ogival head penetrated, the portion enclosed in the plate was violently compressed, whilst the part which remained outside underwent no pressure. This sudden passage from one state to the other, following the line of contact with the exterior surface of the plate, creates a critical state for such a rigid metal as chrome steel; there is a brusque separation of the molecules on the external surface of the projectile; if this separation propagates itself into the interior, rupture will take place. A remedy has been sought in the use of a more or less flexible and ductile envelope, which, placed upon the projectile, would transmit the pressure to it, and at the same time spread it out in a slightly graduated manner. This covering, or cap, of soft steel thus fulfils, from the point of view of the distribution of the pressures, an analogous part to that which is played, from the point of view of the distribution of the material, by the curve which unites the two portions,

of different diameters, of an axle, for the purpose of preventing the formation of a crack in the angle which the curves do away with. Moreover, a projection, or even a burr, is produced on the projectile at the spot where the pressure suddenly ceases. This projection easily scales off, and causes no obstacle to penetration when the exterior surface is a soft metal.

I have just sketched a summary theory of caps, which, according to the hardness of the metal, act like buffers, like projectile hoops, and perhaps, if this rather bold comparison may be permitted, like a sort of lubricating substance, which permits the two surfaces to slide on each other. The projectile, provided with a cap, presents the counterpart of the plate with hardened surface. The first idea of this was, indeed, known in England about the year 1884, I think, as the result of some experiments made with compound plates, in which a sheet of soft iron was interposed between the steel face of the plate and the projectile, or, even, in which the compound plates were attacked from the soft side. As to the experiments with caps, they have been made in different countries, with results which appear to be uniformly satisfactory. In the majority of cases the capped projectiles bear the collision without breaking, and then the increase of resistance of the plates, expressed by R, is diminished to 1·20. Even when the projectile breaks, the cap retains a certain amount of efficiency, and the ratio of R hardly rises above 1·25.

Other solutions than those with caps have been tried with success. Thus, one of the Wheeler-Sterling projectiles, in shot No. 137, Table II., showed itself at least equal to one of the capped projectiles.

If, in the future, the progress made in the manufacture of projectiles suffices to counteract the improvements in plates due to Harveying, there will still remain an incontestable improvement in recent structures as compared with older ones. The wise combinations of horizontal with vertical Harveyed armour, the coal bunkers, the subdivision of the cellular portion, &c., of which Sir William White has given so many beautiful models for the imitation of his rivals, render blows of penetration far less dangerous than they were formerly. To the great benefit of naval architecture, we now know how to protect ourselves better, with a less weight of armour.

TABLE I.

EXTRACTED FROM MR. ELLIS'S TABLE.

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres.	Calibre of the Gun in Millimetres.	Weight of the Projectile in Kilogrammes.	Striking Velocity in Metres.	Thickness of Steel Strictly Perforated, Calculated.	Penetration as Measured. Correction for the Backing Penetrated.	Ratio.	Ratio.	Ratio.
					E	a	p	v	ϵ	e	$R=\frac{\epsilon}{e}$	$\frac{\Delta}{p v^2}$	$\frac{\epsilon}{E}$
GROUP I.—UNBROKEN PROJECTILES: COMPLETE PERFORATION OF THE TARGET.													
8	2	Aug. 23, 1893	Cammell	Krupp	150	120	26	499·9	171	—	—	—	1·14
9	2	„	„	„	150	120	26	539·8	190	—	—	—	1·27
23	5	Aug. 15, 1893	Vickers	Holtzer	152·4	152·4	45·4	597·4	254	—	—	—	1·66
81	21	Ap'l. 12, 1893	„	„	266·7	241·3	143·8	699·8	443	—	—	—	1·66
82	21	„	„	„	266·7	241·3	143·8	649·8	398	—	—	—	1·49
83	21	„	„	„	266·7	241·3	143·8	629·7	381	—	—	—	1·43
108	30	July 21, 1893	„	Chrome steel	268·7	240·4	420·2	540·1	455	—	—	—	1·23
GROUP II.—UNBROKEN PROJECTILES: COMPLETE PERFORATION OF THE PLATES.													
1	1	Aug. 23, 1893	Vickers	Krupp	150	120	26	439·8	142	150+ 2=152	0·93	−0·11	0·95
2	1	„	„	„	150	120	—	479·5	161	150+ 6=156	1·04	0·04	1·07
6	2	„	Cammell	„	150	120	—	439·8	142	150+ 2=152	0·93	−0·11	0·95
11	3	„	J. Brown	„	150	120	—	440·7	142	150+ 3=153	0·93	−0·10	0·95
13	3	„	„	„	150	120	—	499·9	171	150+18=168	1·02	0·02	1·14
60	17	Nov. 14, 1891	Bethlehem	Holtzer	266·7	152·4	45·4	632·4	275	267+ 4=271	1·02	0·02	1·03
62	17	„	„	Firminy	266·7	203·2	95·2	563·9	291	267+ 6=273	1·07	0.09	1·09
63	18	„	Carnegie	Holtzer	266·7	152·4	45·4	632·4	275	267+10=277	0·99	−0·01	1·03
64	18	„	„	„	266·7	152·4	·4	632·4	275	267+11=278	0·99	−0·01	1·03
66	18	„	„	„	266·7	152·4	45·4	632·4	275	267+25=292	0·94	−0·09	1.03
69	19	Nov., 1893	Vickers	Krupp	266·7	152·4	45·4	632·4	275	267+ 4=271	1·01	−0·02	1·03
70	19	„	„	Streiteben	266·7	152·4	50·85	590·1	276	267+16=283	0·98	−0·07	1·03
71	19	„	„	Krupp	266·7	152·4	50·85	590·1	276	267+ 1=268	1·03	0·01	1·03
96	25	July 26, 1892	Bethlehem	Holtzer	266·7	203·2	113·4	518·2	292	267+ 6=273	1·07	0·09	1·09
97	25	„	„	„	266·7	203·2	113·4	518·2	292	267+ 6=273	1·07	0·09	1·09
98	25	„	„	„	266·7	203·2	113·4	518·2	292	267+ 6=273	1·07	0·09	1·09
										Means	1·005	0·00	
GROUP III.—UNBROKEN PROJECTILE: INCOMPLETE PERFORATION OF THE PLATE.													
65	18	Nov. 14, 1891	Carnegie	Holtzer	267	152·4	45·4	632·4	275	248	1·11	0·14	1·03

TABLE I.—(*Continued.*)

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. e	Ratio. $R = \frac{e}{\epsilon}$	Ratio. $\frac{A}{p v^2}$	Ratio. $\frac{\epsilon}{E}$
GROUP IV.—Broken Projectiles: Complete Perforation of the Target, or, at least, of the Plate.													
No Information as to the Thickness of Backing Perforated.													
21	5	Aug. 15, 1893	Vickers	Holtzer	152·4	152·4	45·4	553·2	227	—	—	—	1·49
26	6	,,	J. Brown	,,	152·4	152·4	45·4	597·4	254	—	—	—	1·67
39	10	Dec. 20, 1893	St. Chamond	St. Etienne	160	138·6	30	706	265	—	—	—	1·66
40	10	,,	,,	Holtzer	160	164·7	45	658·0	266	—	—	—	1·66
49	14	,,	,,	St. Chamond	250	240	144	658	408	—	—	—	1·65
50	14	,,	,,	,,	250	240	144	606	363	—	—	—	1·45
51	15	,,	Vickers	,,	250	241 (240.	144	649·8	398	—	—	—	1·59
GROUP V.—Broken Projectiles: Complete Perforation of the Plates.													
First Part.													
7	2	Aug. 23, 1893	Cammell	Krupp	150	120	26	479·5	161	150+14=164	0·98	− 0·03	1·07
14	3	,,	J. Brown	,,	150	120	26	539·8	191	150+ 1=151	1·26	0·28	1·27
16	4	Jan. 18, 1893	Vickers	Holtzer	152·4	152·4	45·4	459·3	190	152+ 1=153	1·14	0·16	1·25
17	4	,,	,,	,,	152·4	152·4	45·4	553·2	248	152+14=166	1·36	0·35	1·63
18	4	,,	,,	,,	152·4	152·4	45·4	597·4	277	152+19=171	1·48	0·42	1·82
19	4	,,	,,	,,	152·4	152·4	45·4	553·2	248	152+ 1=153	1·48	0·43	1·63
25	6	Aug. 15, 1893	J. Brown	,,	152·4	152·4	45·4	553·2	248	152+13=165	1·38	0·36	1·63
27	6	,,	,,	,,	152·4	152·4	45·4	553·2	248	152+23=175	1·30	0·31	1·63
31	7	June 30, 1893	Vickers	,,	152·4	152·4	45·4	553·2	248	152+13=165	1·37	0·36	1·63
36	9	Feb. 7, 1894	J. Brown	,,	152·4	152·4	45·4	553·2	248	152+ 3=155	1·47	0·42	1·63
37	9	,,	,,	,,	152·4	152·4	45·4	597·4	277	152	1·67	0·51	1·82
56	16	Dec. 1, 1892	Vickers	,,	254	228·6	182·8	504·4	440	254+13=267	1·31	0·31	1·73
57	16	,,	,,	Putiloff	254	228·6	182·8	570	523	254+46=300	1·39	0·37	2·06
58	17	Nov. 14, 1891	Bethlehem	Holtzer	266·7	152·4	45·4	632·4	300	267+ 3=270	1·02	0·02	1·13
67	18	,,	Carnegie	Carpenter	266·7	203·2	113·4	518·2	353	267+17=284	1·03	0·04	1·33
69	19	Nov., 1893	Vickers	Krupp	266·7	152·4	50·9	590·1	295	267+ 5=272	0·99	− 0·01	1·11
90	22	Aug. 31, 1893	Cammell	Holtzer	266·7	233·7	172·4	593·7	524	267+32=299	1·38	0·36	1·97
										Means	1·29	0·27	

TABLE I.—(*Continued.*)

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. c	Ratio. $R = \frac{\epsilon}{c}$	Ratio. $\frac{A}{p v^2}$	Ratio. $\frac{\epsilon}{E}$
GROUP V.—Broken Projectiles: Complete Perforation of the Plates.													
Second Part.													
28	7	June 30, 1893	Vickers	Holtzer	152·4	152·4	45·4	459·3	174	—	—	—	1·14
29	7	„	„	„	152·4	152·4	45·4	553·2	227	—	—	—	1·49
30	7	„	„	„	152·4	152·4	45·4	597·4	254	—	—	—	1·67
38	9	Feb. 7, 1894	J. Brown	„	152·4	152·4	45·4	553·2	227	—	—	—	1·49
41	11	Dec. 20, 1893	Vickers	St. Etienne	152·4	139·7	29·9	705	262	—	—	—	1·72
42	11	„	„	Holtzer	152·4	160	44·9	658	274	—	—	—	1·80
45	12	Aug. or Sept., 1893	„	„	155	152·4	40·8	599·8	236	—	—	—	1·52
46	13	Sept. 26, 1893	Châtillon et Commentry	Châtillon et Commentry	170	160·5	45	614	248	—	—	—	1·46
91	23	Oct. 10, 1893	J. Brown	Holtzer	267	233·7	172·4	620·2	439	—	—	—	1·65
92	23	„	„	„	267	233·7	172·4	550·7	370	—	—	—	1·39
100	27	Oct. 26, 1893	„	„	267	233·7	172·4	620·2	439	—	—	—	1·65
107	30	July 21, 1893	Vickers	Chrome Steel	369	340	420	624·8	561	—	—	—	1·52
GROUP VI.—Broken Projectiles: Incomplete Perforation of the Plates.													
3	1	Aug. 23, 1893	Vickers	Krupp	150	119·9	26	499·9	171	61	2·80	0·77	1·14
12	3	„	J. Brown	„	150	119·9	26	479·4	161	64	2·53	0·73	1·07
33	8	Nov. 8, 1893	Cammell	Holtzer	150	119·9	26	553·2	227	76	2·98	0·78	1·51
34	8	„	„	„	150	119·9	26	597·4	254	86	2·96	0·78	1·69
35	9	Feb. 7, 1894	J. Brown	„	150	119·9	26	459·3	174	43	4·03	0·86	1·16
43	12	Aug. or Sept., 1893.	„	„	150	119·9	40·8	449·9	157	32	4·94	0·89	1·05
44	12	„	„	„	150	119·9	40·8	549·8	209	38	5·4	0·91	1·39
47	13	Sept. 26, 1893	Châtillon et Commentry	Châtillon et Commentry	170	160·5	45	634	260	76	3·42	0·82	1·53
52	16	Dec. 1, 1892	Vickers	Putiloff	254	152·4	39·5	663·5	267	127	2·10	0·65	1·05
53	16	„	„	„	254	152·4	39·5	660	265	127	2·08	0·64	1·05
54	16	„	„	„	254	152·4	39·5	663·5	267	127	2·10	0·65	1·05

TABLE I.—(*Continued.*)

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. e	Ratio. $R = \frac{\epsilon}{e}$	Ratio. $\frac{\Lambda}{p v^2}$	Ratio. $\frac{\epsilon}{E}$
GROUP VI. (*Continued.*)—Broken Projectiles: Incomplete Perforation of the Plates.													
55	16	Dec. 1, 1892	Vickers	Holtzer	254	152·4	39·5	664	267	127	2·10	0·65	1·05
59	17	Nov. 14, 1891	Bethlehem	,,	267	152·4	45·4	632·4	275	173	1·59	0·48	1·03
61	17	,,	,,	,,	267	152·4	45·4	632·4	275	178	1·55	0·46	1·03
68	19	Nov., 1893	Vickers	Streiteben	267	152·4	50·8	590·1	270	249	1·09	0·11	1·01
72	19	,,	,,	,,	267	240·1	214·5	486·8	302	38	7·93	0·95	1·13
73	20	Nov. 1, 1892	,,	Holtzer	267	152·4	45·4	601·4	256	102	2·52	0·73	0·96
74	20	,,	,,	,,	267	152·4	45·4	601·4	256	102	2·52	0·73	0·96
75	20	,,	,,	Palliser	267	152·4	44·5	601·4	252	76	3·31	0·81	0·94
76	20	,,	,,	,,	267	152·4	44·5	601·4	252	76	3·31	0·81	0·94
77	20	,,	,,	Holtzer	267	152·4	45·4	601·4	256	102	2·52	0·73	0·96
78	20	June 1, 1893	,,	,,	267	233·7	172·4	517·5	339	152	2·22	0·67	1·27
79	20	,,	,,	,,	267	233·7	172·4	551·0	371	232	1·60	0·48	1·39
80	21	April 12, 1893	,,	,,	267	241·3	141	579·7	334	100	2·08	0·66	1·29
89	22	Aug. 31, 1893	Cammell	,,	267	233·7	172·4	551	371	203	1·82	0·57	1·39
93	24	July 30, 1892	Bethlehem	,,	267	203·2	113·4	518·2	292	85	3·44	0·82	1·09
94	25	July 26, 1892	,,	,,	267	203·2	113·4	518·2	292	85	3·44	0·82	1·09
95	25	,,	,,	,,	267	203·2	113·4	518·2	292	85	3·44	0·82	1·09
99	26	Nov. 9, 1893	Cammell	,,	267	233·7	172·4	620·2	439	254	1·73	0·54	1·64
103	29	Feb. 11, 1893	Bethlehem	,,	355	254	226·8	448·7	308	51	6·05	0·92	0·87
104	29	,,	,,	,,	355	254	226·8	566·6	429	127	3·38	0·82	1·21
105	29	,,	,,	,,	355	254	226·8	597·0	462	152	3·03	0·79	1·30
106	29	,,	,,	,,	355	254	226·8	627·5	497	127	3·91	0·85	1·40
									Means ..	..	2·78	0·70	1·40
GROUP VII.—Slight Penetration, no Figures Given.													
24	6	Aug. 15, 1893	J. Brown	Holtzer	152·4	152·4	45·4	459·3	174	—	—	—	1·14
32	8	Nov. 8, 1893	Cammell	,,	152·4	152·4	45·4	459·3	174	—	—	—	1·14
84	22	May 12, 1893	,,	,,	267	152·4	45·4	597·4	254	—	—	—	0·95
85	22	,,	,,	,,	267	152·4	45·4	597·4	254	—	—	—	0·95
86	22	,,	,,	Palliser	267	152·4	44·5	597·4	250	—	—	—	0·94
87	22	,,	,,	,,	267	152·4	44·5	597·4	250	—	—	—	0·94
88	22	,,	,,	Holtzer	267	152·4	45·4	597·4	254	—	—	—	0·95

TABLE I.—(*Continued.*)

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. e	Ratio. $R=\frac{\epsilon}{e}$	Ratio. $\frac{A}{pv^2}$	Ratio. $\frac{\epsilon}{E}$
GROUP VIII.—Results Insufficiently Defined.													
4	1	Aug. 23, 1893	Vickers	Krupp	150	120	26	539·8	190	—	—	—	1·27
5	1	„	„	„	150	120	26	573	207	—	—	—	1·38
10	2	„	Cammell	„	150	120	26	573	207	—	—	—	1·38
20	5	Aug. 15, 1893	Vickers	Holtzer	152	152	45·4	459·3	174	—	—	—	1·15
22	5	„	„	„	152	152	45·4	553·2	153	—	—	—	1·01
48	13	Sept. 26, 1893	Châtillon et Commentry	Châtillon et Commentry	170	160·5	45	653	271	—	—	—	1·59
101	28	Aug. 26, 1893	Vickers	Krupp	305	279·4	230·4	480	309	—	—	—	1·02
102	28	„	„	„	305	152	50·8	663	320	—	—	—	1·05

TABLE II.

Harveyed Plates.

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. e	Ratio. $R=\frac{\epsilon}{e}$	Ratio. $\frac{A}{pv^2}$	Ratio. $\frac{\epsilon}{E}$
GROUP Ia. is Deficient.													
GROUP IIa.—Unbroken Projectile: Complete Perforation of the Plate.													
109	31	Aug. 28, 1896	Krupp	—	368	305	325·75	656	563	368+33=401	1·40	0·38	—
GROUPS IIIa. and IVa. are Deficient.													
GROUP Va.—Broken Projectiles: Complete Perforation of the Plate.													
110	32	Sept. 4, 1895	Carnegie	Wheeler Sterling	355	305	388·55	548	491	355+ 8=363	1·35	0·35	—
111	33	Feb. 27, 1896	„	„	305	305	324·60	430	307	305+ 5=310	0·99	−0·01	—
112	34	Mar. 19, 1897	St. Chamond	St. Chamond	276	274·4	216	574	389	276	1·41	0·38	—
113	34	Mar. 26, 1897	„	„	276	240	144	635	388	276	1·41	0·38	—
114	34	„	„	„	276	240	144	680	428	276+30=306	1·40	0·38	—
115	35	Aug. 17, 1896	Châtillon et Commentry	„	249	240	144	689	436	250	1·74	0·55	—

TABLE II.—(*Continued.*)

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres.	Calibre of the Gun in Millimetres.	Weight of the Projectile in Kilogrammes.	Striking Velocity in Metres.	Thickness of Steel Strictly Perforated, Calculated.	Penetration as Measured. Correction for the Backing Penetrated.	Ratio.	Ratio.	Ratio.
					E	a	p	v	ϵ	e	$R=\frac{\epsilon}{e}$	$\frac{\Lambda}{p v^2}$	$\frac{\epsilon}{E}$
GROUP VIa.—Broken Projectiles: Incomplete Perforation of the Plates.													
116	36	Jan. 11, 1897	Châtillon et Commentry	St. Chamond	350	320	345	525	405	153	2·65	0·74	1·16
117	36	,,	,,	,,	340	320	345	560	445	170	2·62	0·71	1·31
118	36	,,	,,	,,	330	320	345	650	550	230	2·39	0·71	1·67
119	37	Aug. 28, 1896	,,	,,	340	320	345	523	403	208	1·94	0·60	1·19
120	37	,,	,,	,,	340	320	345	559	443	270	1·64	0·50	1·30
121	37	,,	,,	,,	340	320	345	620	514	300	1·71	0·53	1·51
122	38	Sept. 18, 1896	St. Chamond	,,	340	320	345	521	401	185	2·17	0·66	1·18
123	38	,,	,,	,,	340	320	345	558	442	155	2·85	0·77	1·28
124	38	,,	,,	,,	340	320	345	620	514	260	1·98	0·62	1·51
125	39	,,	MM. Marrel	,,	320	320	345	527	408	118	3·46	0·82	1·28
126	39	,,	,,	,,	320	320	345	563	448	203	2·21	0·67	1·40
127	40	Jan. 20, 1897	Creusot	,,	330	320	345	519	399	150	2·66	0·75	1·21
128	40	,,	,,	,,	330	320	345	554	438	226	1·99	0·62	1·33
129	41	April 15, 1897	Châtillon et Commentry	,,	300	240	144	681	429	160	2·68	0·75	1·43
130	42	Mar. 19, 1897	St. Chamond	,,	276	271·4	216	538	354	160	2·21	0·67	1·28
131	35	July 10, 1896	Châtillon et Commentry	,,	249	240	144	620	375	150	2·50	0·72	1·51
132	35	,,	,,	,,	249	240	144	650	401	205	1·96	0·61	1·61
133	43	April 22, 1897	Creusot	,,	160	138·6	30	656	239	120	1·99	0·61	1·49
134	44	Mar. 15-16, 1895	Krupp	,,	300	280	230·6	552·50	377	134	2·81	0·77	1·26
135	45	,,	,,	,,	300	305	324·5	534·60	419	90	4·66	0·88	1·40
136	45	,,	,,	,,	300	305	324·5	575·70	466	180	2·59	0·74	1·55
137	46	Feb., 1896	Carnegie	Wheeler Sterling Carpenter	375	300	389·55	429·50	355	331	1·07	0·09	0·95
138	32	Sept. 4, 1895	,,		355	254	226·8	451	310	90	3·44	0·82	0·87
139	32	,,	,,	,,	355	254	226·8	565	427	279	1·53	0·19	1·20
140	47	Nov. 17, 1896	,,	,,	338	254	225·9	400	260	100	2·60	0·74	0·77
141	47	,,	,,	,,	338	254	226·8	530	390	180	2·17	0·66	1·15
142	48	,,	,,	,,	254	203	95·25	640	319	178	1·96	0·61	1·37
143	49	Jan., 1896	,,	Wheeler Sterling Carpenter	203	150	45·56	553	231	50	4·62	0·88	1·14
144	50	Jan. 10, 1896	,,		203	152	45·35	562	233	50	4·66	0·88	1·15
145	51	Feb. 12, 1896	,,	,,	177	152	45·35	493	193	50	3·86	0·85	1·09
146	52	Feb., 1896	,,	,,	175	150	45·36	486	192	50	3·84	0·85	1·10
147	53	,,	,,	Wheeler Sterling	175	150	45·50	552	231	75	3·08	0·79	1·32

TABLE III.

NON-HARVEYED PLATES.

No. of Shot.	No. of the Plate.	Date of Trial.	Manufacturer of the Plate.	Source of Manufacture or Nature of the Projectile.	Thickness of the Plate in Millimetres. E	Calibre of the Gun in Millimetres. a	Weight of the Projectile in Kilogrammes. p	Striking Velocity in Metres. v	Thickness of Steel Strictly Perforated, Calculated. ϵ	Penetration as Measured. Correction for the Backing Penetrated. e	Ratio. $R = \frac{\epsilon}{e}$	Ratio. $\frac{A}{p\,r^2}$	Ratio $\frac{\epsilon}{E}$
										GROUP Ip.—			
										GROUP IIb.—UNBROKEN PROJECTILES: COMPLETE PERFORATION OF THE PLATES.			
148	54	Oct. 25, 1895	Marrel	Marrel	290	274·4	216	422	250	290+ 1=291	0 86	- 0·23	0 86
149	54	„	„	„	315	274·4	216	485	305	315+ 5=320	0 95	- 0 07	0 97
150	55	Jan. 10 1896	Châtillon et Commentry	„	300	274·4	216	487	307	300+ 7=307	1 00	0 00	1 02
151	56	Feb. 7, 1896	St. Chamond	„	305	274·4	216	450	274	305+ 4=309	0 89	- 0·18	0 90
152	57	May 1, 1896	Creusot	St. Chamond	250	240	144	428	221	250+ 3=253	0·87	- 0 21	0 88
153	58	June 5, 1896	St. Chamond	Marrel	265	274·4	216	391	225	265+ 2=267	0 84	- 0 27	0 85
154	58	„	„	„	265	274·4	216	452	276	265+ 9=274	1·01	0 01	1 04
155	58	„	„	„	265	274·4	216	480	301	265+12=277	1·09	0.11	1·14
156	59	Feb. 22, 1896	Marrel	St. Chamond	250	240	144	423	217	250	0 87	- 0 22	0 87
157	59		„	„	245	240	144	487	266	245+10=255	1 04	0 06	1·09
158	60	Aug. 17, 1896	„	Firminy	230	194	75	498	216	230	0 94	- 0 09	0·94
159	60	„	„	„	230	194	75	575	264	230+25=255	1·04	0·05	1·15
160	61	Dec. 30, 1896	Creusot	„	220	194	75	495	214	220+ 5=225	0 95	- 0 07	0 97
161	62	Aug. 28, 1896	Marrel	Marrel	190	164·7	45	546	204	190+ 9=199	1·03	0 03	1·07
									Means		0 96	0 08	1 07
										GROUP IIIb.- UNBROKEN PROJECTILES: INCOMPLETE PERFORATION OF THE PLATES.			
162	63	May 15, 1896	Creusot	St. Chamond	379	340	420	417	315	336	0·94	- 0·10	0·83
163	63	„	„	„	379	340	420	479	384	350	1·10	0·12	1·01
164	64	Aug. 22, 1896	St. Chamond	„	368	340	420	408	305	330	0 92	- 0·12	0·83
165	65	Jan. 10, 1896	Châtillon et Commentry	Marrel	300	274·4	216	424	252	295	0·85	- 0 25	0·84
										Mean	0 95	- 0·09	0 84
										GROUP IVb. IS DEFICIENT.			
										GROUP Vb.—BROKEN PROJECTILES: COMPLETE PERFORATION OF THE PLATES.			
166	56	Feb. 7, 1896	St. Chamond	Marrel	305	274·4	216	518	336	305+18=323	1·04	0 05	1·10
167	56	„	„	„	305	274·4	216	540	356	305+17=322	1·11	0·13	1·17
168	57	May 1, 1896	Creusot	St. Chamond	250	240	144	495	272	250+14=264	1 03	0 04	1·09
169	66	June 26, 1896	Châtillon et Commentry	Marrel	172	164·7	45	513	187	172+ 7=179	1·05	0 06	1·09
										Means	1·07	0·07	1·11
										GROUP VIb. IS DEFICIENT.			

DISCUSSION.

Mr. Charles Ellis (Associate): My Lord, and Gentlemen, I am sure everyone who has listened to M. Bertin's most masterly paper on the subject of armour must agree with me that it is extremely difficult for anyone who has not had the opportunity of reading the paper beforehand to present any remarks to an Institution of this kind which can be of any permanent value. I deeply regret that it was impossible for me to obtain a copy of this paper before I came into the room this morning, because I am sure it deserves very careful examination before we can properly appreciate its value to this Institution. M. Bertin has done me the honour of alluding to a paper which I had the pleasure of reading some years ago to this Institution. Curiously enough, his researches have brought him to the same conclusion with regard to the increase of resistance given by Harveyed armour as I presented to the Institution upon that occasion. I find that M. Bertin on page 2 of his paper states that, in his opinion, the results of the trials to which he has referred show that the resisting power of Harveyed steel plates, over ordinary steel plates, would amount to about 50 per cent. That, my Lord, is the same figure which I had the temerity, I may say, to place before the Institution three years ago, and I think that Sir William White, and every other gentleman who has had the opportunity of noting the progress of Harveyed armour during the last three years, will agree with me when I say that the figure named by M. Bertin is fully borne out by the facts. My Lord, with regard to what I may call the more technical part of this paper, it is, as I have said, impossible to do it justice upon this occasion. There are, however, one or two points in connection with the paper to which I should like to refer. M. Bertin, on page 13, draws a very considerable distinction between the extra resistance of Harveyed thin armour, as compared with ordinary steel, and the resistance of Harveyed thick armour, as compared with ordinary steel, and he thinks that the superiority of the Harveyed armour, in the case of thick plates, is nothing like so marked as it appears in the case of thin armour. Now, my Lord, I think three years ago I and everybody else would have been inclined to have agreed with M. Bertin in this matter; but, although he has not specially referred to the improvements which have been recently made in Germany by Herr Krupp, I think it is palpable to everybody who has had the particulars of some of the trials made by Herr Krupp's firm, that Herr Krupp has, I may almost say, mastered the difficulty which originally presented itself with regard to thick armour, and, although we may all claim that Herr Krupp's improvements are merely improvements on Harveyed armour, yet still, there is no doubt that some of the results which he has obtained show that, not only can you get the same proportionate resistance in the case of thick armour as you could before in thin armour, but that you can get it with, practically, an absence of cracking. That is in itself a very wonderful result. No doubt in the tables which M. Bertin has presented to us I shall find notes of some of Herr Krupp's trials, but I thought it well to point out to the Institution that, during the past three years armour plate makers have not absolutely stood still. Improvements have been made, and I hope will constantly be made. I am sure I, for one, am extremely grateful to M. Bertin for presenting this paper to us, and, as I said before, I only wish that I could have had an opportunity of dealing more properly with it.

Monsieur Émile Bertin (Hon. Member): My tables relating to firing experiments carried out from the end of 1893 up to date do not, in any way, pretend to be complete. In order to prepare them, I have put all the documents which were at my disposal under contribution, such, for instance, as the results obtained in France and those published, as far as my knowledge goes, in the newspapers relating to trials made outside France, but nothing more. If my paper ultimately leads to the

knowledge of results which are wanting to me, and thus helps in establishing the laws of the resistance of plates to penetration by projectiles with more precision than I have done, I shall congratulate myself most heartily.*

Sir WILLIAM WHITE, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): My Lord Hopetoun, Ladies and Gentlemen, I still hope that some of the representatives of foreign armour plate making firms who are here will favour us with observations. While they are making up their minds to do that, there are one or two things I should like to say. It has fallen to my lot during the last ten years to see more experiments made on armour plates than almost any other person could have seen, and I, therefore, speak with special knowledge of the subject. M. Bertin has been very careful to guard himself, and to point out that, in the analysis he has attempted, he quite recognises that he has not all the facts that he would desire to have. There are two great groups of trials which appear in his paper for which elements of importance are, avowedly, quite unknown. In the one class, there has been complete penetration of the target, and the remaining velocity and energy are not recorded. There are, it is true, examples where the remaining energies and velocities are reported; but, in numerous instances, where a target has been penetrated there is no means of knowing how much margin there was in the power of attack. In the second class, the converse case occurs, and in later years, I am glad to say, this has been a very common case. An attack is made on a plate which, under former conditions, would have resulted in complete penetration, but now the only effect is a "dent" in the plate. In these instances the unknown quantity is, how much margin of strength the plates possess, or what would ensure complete perforation. Now, it is a very remarkable circumstance that, in seeking certain qualities of defence in armour, conditions may exist such that, almost up to the moment of yielding, there is little or no indication of the approach to yielding. When plates of an experimental nature have been fired at with progressive velocities to determine their limit of resistance to perforation, and their quality has been such that, although Harveyed, there has been no tendency to cracking, it sometimes happens that a critical stage occurs, and with a small increase in energy complete perforation takes place, almost without warning. This perforation, however, did not occur always in the manner which M. Bertin has indicated. The failure of the metal did not follow the lines of his diagram. Instead of that, there was driven out by the projectile an almost cylindrical block of metal which formed an "advance guard" to the projectile itself. This kind of experience illustrates what all metallurgists know, viz., that, in improving one quality—say, freedom from cracking—it is possible to produce a material which yields in some unexpected way. Now, I do not desire for a moment to suggest that M. Bertin could have carried his analysis any further with the materials at his disposal. I think that is impossible. We are under obligation to him for having devoted his great ability, and also so much industry, to such an analysis as he has made of trials which have been recorded. But, from the practical point of view, I should like to say that my conviction is that we who are the users of armour, as well as metallurgists who have to make armour, can never dispense with a complete study of actual firing trials on the spot. No report that I have ever read on any armour plate trial conveyed to my mind all the facts. One wants to be there, to see the whole thing, to see the plate taken down, to see the condition of the target behind the plate. Apart from that information it is not possible to get a fair and complete judgment of what the defence may be. There are so

* To my great regret, I became aware too late of the important paper published by Signor R. Bettini in Nos. 3 and 4 of the *Rivista Marittima* for 1897. The results which the author gives, especially those of trials at Essen and Maggiano, would have enabled me to add a good deal to my tables.

many ways in which experimental results may be treated, or recorded, or appreciated. One way, which was much in vogue until quite recently, was to take the total energy of attack in foot tons on a plate, and equate it to the weight of the plate in tons. That was a very favourite method, and is not even yet abandoned. With hard-faced armour a plate may be badly cracked, almost to fragments, and yet, if it is held up against the target by good bolts, the almost separated pieces of plate between the cracks will show almost the full resistance to perforation, of the unbroken plate. In view of this fact it is obvious that the method of expressing energy of attack in foot tons per ton weight of plate is not satisfactory. I quite agree with what Mr. Charles Ellis has said respecting the advance which has been made in armour during the last three years. M. Bertin has fully acknowledged that this advance has put upon an entirely different footing the processes of treatment of armour, especially of thick plates. This advance has been an international matter, and I am glad to acknowledge it here. The use of steel armour, as we all know, was largely due to improvements made in France. The use of compound armour was an English device, and these two long went on, side by side, and I do not think there was much to choose between them. Then came the great improvement of Harveying plates, which was brought to a practical conclusion in America, and now we have a further improvement—I won't say final—which we owe to German skill and perseverance. In all countries of the world where warships are produced, whatever may be the processes used for giving the best defence, it is our own business, I presume, to use them. We were ready enough to adopt "all-steel" armour when it could be made equal to compound. We lost no time in adopting the Harveying process when it came before the world, and we have lost no time in adopting the Krupp processes as they have been introduced. If anybody else will give us a better defence for a given weight, you may depend upon it that, in England, that defence will be used. I venture to hope that, before this discussion closes, we shall have from the German side and the American side some contribution to our information. This paper has involved very much work, and, as Mr. Charles Ellis very properly said, cannot be discussed off hand, but requires close study. Perhaps Mr. Charles Ellis, instead of contributing a note to the discussion, as he contemplated, might, at some future time, take up this matter again, and give us another paper in the Transactions. That will be the best way of dealing with a very important subject.

Sir WILLIAM WHITE: Perhaps M. Bertin, when replying, will be good enough to give further particulars on the subject of the spiral lines shown on Plate I.

Monsieur ÉMILE BERTIN (Hon. Member): The waves in spirals (not the vibrations) produced by impact on the exterior surface of plates appear to present something more than the interest of curiosity, when regarded from the point of view of the study of armour plates; they show that the lateral pressure is transmitted to long distances, and that, consequently, the plates work over a large extent. It is quite true that real punching sometimes takes place, as Sir William White has remarked; but under other circumstances, especially when the original point is sharp, and the material of the plate very soft, the metal is, to a great extent, driven sideways, and this motion is accompanied by undulating movements, which testify to the true fluidity of the material, and which manifest themselves on the surface by the curves which have been photographed after the blow. These curves are produced on both faces of the plate; they are met with most frequently on the rear face, where they are most pronounced. They originate only at a certain distance from the point of impact of the projectile, beyond the region of the local deformations of the surface, which are raised on the front face like lips, and like bulges on the rear face; but, it is very probable that the undulations of which they are the trace, originate at the place of contact of the projectile with the heart of the plate, where the

metal was unable to yield; afterwards the compression, propagating itself laterally, reaches the surfaces of the plates, where it becomes visible by the relief of the undulations which are produced. These curious molecular movements of the steel are connected with quite a number of phenomena of the same nature, which have been the subject of minute study—for the most part unpublished—by the artillery officers of St. Thomas d'Aquin at Paris. I do not think that I commit any indiscretion in now borrowing from these studies. My recollection of the facts is of quite recent origin, and will show the importance of the subject from the scientific point of view. Every effort of tension or compression, when exercised on a metallic mass, gives rise to undulatory motion, consisting, sometimes of solitary waves and sometimes of a series of successive waves. These waves are sometimes stationary, as in the case of a splash, but more often they are endowed with a propagatory chopping (standing waves) motion. One singular and universal property of these waves, whatever may be their nature and whatever the metal, is to make always a certain angle, which is sensibly the same at all points, with the direction of the tensile or compressive effort. This angle for iron and steel lies within 50° and 60°. As a consequence of the laws of symmetry we find two networks of waves spread out on all sides of the lines of tension and compression. A thin and very homogeneous plate examined after having been submitted to a tensile force, shows, generally, two solitary hollow waves which cut the middle line at the same point and form a perfect X. A block examined after compression shows two complete networks of waves in relief, which cover the entire space between the points of compression, and which die away as they curve outwards from the line of transmission of the force. If the compression is exercised at three points, in such a way as to produce flexure, the waves, while obeying the above simple laws, describe curves of a different appearance. In plates under fire the lines of compression radiate out in straight lines around the projectile; the waves consequently form Archimedian spirals, as shown in Plate I., where their angle is about 53° with the rays, and varies about 4°, more or less. The propagation of a wave in metal may be a simple effect of hammer-hardening. Every local deformation, whether of extension or the reverse, produces hardening, and thus increases the resistance of the metal at the point where it is produced; consequently, every deformation which is commenced at an originally weak point is soon arrested there; then it continues into the neighbouring region, which has not yet been hammer-hardened, and so on. There remains to be explained the variety of the waves, which has already been indicated summarily. It is, above all, necessary to find out the cause of the obliquity, which shows us that metals are obliged to deform themselves along the sides of sorts of parallelograms, whereas in fluids, on the other hand, the waves are formed freely, and their generatrices are perpendicular to the forces which produce them. Whatever may be the cause, we see in these undulatory movements of metals a new manifestation of the mobility of their molecules in relation to one another. Old investigations, which proved the slow flow of metals under the prolonged action of permanent forces, had already brought this mobility to light.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): I am quite certain it is your wish that a very hearty vote of thanks be recorded to M. Bertin for the very excellent paper that he has favoured us with.

NON-FLAMMABLE WOOD.

By Charles E. Ellis, Esq., Associate.

[Read at the International Congress of Naval Architects and Marine Engineers, at the Imperial Institute, July 6, 1897; the Right Hon. the Earl of Hopetoun, G.C.M.G., President, in the Chair.]

An experiment which was recently made in London, with the consent of H.M. Office of Works, has drawn public attention to a novel method of rendering wood incapable of flaming or transmitting flame. Such a discovery cannot fail to be of interest to members of this Institution, and the Council have done me the honour of allowing me to bring the matter before you at this meeting.

As long ago as 1625 a patent was granted by the English Patent Office to one Beale for "a dressing for shippes and other vesselles as their mastes, deckes, tackles, sayles, and other furnitures, that they maie be preserved in fight at sea from burning or consumynge by wildefyer or gunpowder."

From that period forward countless efforts seem to have been made to obtain the desired result, but most of the experiments appear to have been conducted on the lines of soaking or coating timber with various preparations, and no plan seems to have been devised for securing what is absolutely essential, namely, that the fire-resisting treatment shall permeate the heart of the wood so as to render it internally as well as externally fire-proof.

The earlier inventors naturally lay under great disadvantages. Little was known of the chemical and physical qualities of wood, which, when they are thoroughly understood, appear to point to the practical solution which has been obtained under the discovery now about to be noticed.

The different kinds of timber vary much in analysis, but (taking an average) wood may be said to contain about 40 per cent. of water, 58 per cent. of combustible elements, and nearly 2 per cent. of incombustible elements, or ash, comprising various salts of lime, potash, and the like. In structure it consists of a number of cells or vessels, varying also with every kind of wood, in or around which the combustible materials, above referred to, are contained. This structure can be readily seen by an examination of the fine sections of wood which I am able to show to the Institution.

It is obvious that the main difficulty of getting rid of the combustible elements and substituting others lies in providing means for treating the cells without rupturing their delicate structure, and so deteriorating the value of the timber.

It is claimed for the new non-flammable wood that this difficulty has been successfully overcome. By this process the timber is placed in a cylinder, and a vacuum is formed. Steam is then admitted, causing the moisture in the wood to vaporise, the products of the vapour being drawn off. A vacuum is again formed, and the saturating liquid, containing certain salts, is forced in fine spray mixed with steam into the cylinder until the wood is thoroughly impregnated. The wood is then dried, and is ready for use. The salts which are thus forced into the wood by the process of saturation retard the rapid carbonisation of the wood under high heat, and particularly the generation of combustible gases, which are the cause of flame.

That wood so treated is incapable of supporting or conveying flame was conclusively proved at the experiment above alluded to. Two buildings were erected similar in design, one being built of ordinary and the other of treated wood. They were about 11 ft. square, with the floors about 4 ft. from the ground, the lower portions of the walls below the floor being formed of open trellis work, so as to allow for circulation of air and flame. The height of the buildings was about 30 ft. from the ground to the top of the wooden chimney. The framework and walls were constructed of pine internally fitted with linings of ash, oak, birch, and mahogany. Equal quantities of dry wood, saturated with petroleum, were piled to windward of each building, and simultaneously ignited. The untreated building was ablaze in a few minutes, and in half an hour was completely destroyed. The treated building, on the other hand, showed no signs of burning, except where the trellis work and walls were charred by actual contact with the flames from the burning firewood. On entering the building at this stage it was found to be quite cool inside, both on its walls and floor.

A further test was then made of the treated building by igniting a large heap of shavings and firewood inside the structure. By means of open doors and windows and the high open chimney shaft a strong draught was created. The flames from the burning wood rushed up through the chimney, melting the glass in the windows, the fire burning furiously for about twenty minutes. On entering the building it was found that it had been charred, as in the previous experiment, but that structurally it was quite uninjured. A box made of treated wood which had been inside the house during the fire was also found externally charred, but its contents remained in perfect condition. The success of the experiment above described was apparent to all who witnessed it.

Similar trials, of which I have the particulars, have been made in the United States; but, as the details do not differ from the London experiment, it is not necessary to further refer to them. A number of laboratory tests on a small scale have also been

made; but, in view of the results given by the severe practical demonstrations above referred to, it is sufficient to say that they fully confirm the conclusion that the treated wood is absolutely incapable of transmitting flame; in all cases the results are identical, with the fiercest fire only local carburisation is caused.

Before dealing with the use of such wood in naval architecture it may be desirable to refer to a few of its characteristics. The treated wood weighs from 8 to 15 per cent. more than ordinary wood of the same kind, the increase of weight varying with the character of the wood employed. In some cases it takes a slightly deeper colour, but its general appearance is identical. There appears to be no considerable difference in working it, and, like ordinary wood, it is capable of receiving a high polish. So far as experience goes the treatment is of a permanent character. Pieces of wood have been tested after a lapse of two years since the treatment, and found to possess all the non-flammable qualities, and, in the opinion of eminent chemists, lapse of time cannot diminish the incombustibility of the wood, since stability and non-volatility are the characteristics of the chemicals employed.

It is also stated by experts that the process of saturation has a valuable preservative action, and that wood treated by the process will be largely protected from dry-rot, insects, &c. That this is, at least, probable is evident from the consideration pointed out by Laslett—that it is the combustible elements of timber which affect its durability, not only by their liability to oxidise in the open air, but by reason of their being the very elements which are consumed by various insects and fungi, and other organisms which destroy the wood. A process, therefore, which consists in the treatment of timber in the manner described would appear *à priori* to be as efficacious in its preservative effect as in ensuring incombustibility.

From the foregoing remarks it would appear that, while, on the one hand, no practical objections arise to its use, the so-called non-flammable wood in no way belies its name, and, in a most important particular, is probably more suitable than ordinary timber. It is for the naval architect to decide whether, and to what extent, wood so treated should be utilised in shipbuilding. The arguments for its use rest on two grounds: (1) as being non-flammable, it is obviously, so far at least, superior to ordinary wood; (2) by reason of its low conductivity of heat it may be most usefully employed in substitution for material with greater conductive power.

With regard to (1), the risks of fires at sea are so terrible that little need be said on this part of the case. As to the danger of fire in naval warfare it is not necessary to go back further than the battle of the Yalu. Mr. H. W. Wilson, in "Ironclads in Action," points out that the number of fires which occurred on board the ships of both combatants was a striking feature of that battle. The *Lai Yuen* was so severely burnt that nothing but her ironwork remained above the water-line. The *Ting Yuen* and the *Ching Yuen* were on fire three times, the *Chen Yuen* eight times, while four other

vessels were on fire at least once. "The Japanese," says Mr. Wilson, "suffered somewhat from fire, though not so seriously as the Chinese. Doubtless their ships were in better order, and discipline on board them was more thoroughly maintained. It is also probable that less wood was used in the construction of their vessels. The fires seem to have been the effect of gunpowder alone." It may naturally be said that with better discipline such fires could not have assumed such serious proportions. No doubt this is so, but the main point remains that, if a fire breaks out in a naval engagement, men must be drawn from their ordinary duties, whether from the stokehold, or gun batteries, or elsewhere, to put the fires out, thus creating considerable disorganisation, and possibly panic. I am, of course, aware that, in the most modern vessels of war, the substitution of metals for wood has reduced the danger of fire, possibly to a minimum, but I shall await with interest the opinions of those best qualified to judge as to whether it would not be desirable to revert to some extent to the old material now that the danger of fire is practically over. The Navy Department of the United States has already specified that all wood used in the construction of vessels recently ordered (I believe about thirty in number) shall be treated by the new process, and the Japanese Government, who are always desirous of embodying in their designs any modern improvement, have also specified the treated wood for all timber used in the construction of the two new cruisers now building in American shipyards.

The second point above alluded to, namely, the low degree of conductivity of wood, points to its use in many cases where, hitherto, wood could not be used on account of the danger of fire. I may instance ammunition boxes, particularly where they contain smokeless powder, which, as is well known, is of so sensitive a character as to be materially affected by changes of temperature. It is also suggested that cylinders, and even boilers, might be cased with the wood, and thus materially increase the efficiency of the steam service, and further conduce to the comfort and health of the men on board. In this connection it is of interest to note that, in experiments that have been recently made, it was shown that the conductivity of treated wood was about 50 per cent. less than that of ordinary wood of the same kind.

Great radiation of heat is necessarily consequent on the use of metals, and it is submitted that many uses may be found, whether on war, passenger, or cargo steamers, for a material of less conductivity. In the case of ships passing through the tropics this point becomes one of the first importance.

In the above remarks I have only attempted to dwell on what appear to me to be the salient features of non-flammable wood, and look forward with much interest to hearing the opinions of professional members of the Institution who are far better qualified to judge of the value of the invention than myself.

DISCUSSION.

Mr. D. W. Taylor (Member): My Lord, as reference has been made in the paper to the practice of the United States, perhaps a statement of our experience with this non-flammable wood may be of interest to you. It was brought to the attention of, and adopted by our Navy Department in 1895, two years ago, and since then it has been used largely in all of our ships. We have at present eight gunboats just completed, fitted with this non-flammable wood throughout. There have been numerous reports on it, and various experiments made. I see a gentleman here who has made a number of the experiments, and hope we shall hear something from him. I regret I did not know, before leaving home, that this question was coming up, because I should then have gone over our reports, and been in a position to give you some accurate data. Speaking generally, however, our experience has been that the strength is somewhat decreased by the treatment, but not to such an extent as to interfere with the use of the wood on an iron or steel ship. When it was first introduced there was complaint of trouble with working it, but the difficulties have been overcome. It appears to require more care, and the workmen who are not accustomed to it naturally object to it at first. As regards the durability, we have not had sufficient experience yet to speak. The vessels on which it has been used are mostly small gunboats and torpedo-boats, but it is now being used on a somewhat larger scale in our battleships.

Admiral H. Boys (Associate): My Lord, I should like to ask a question of the lecturer on this subject. It is this: immediately after the Chinese-Japanese war, where dangerous fires from the bursting of shells occurred on board several ships at the battle of Yalu, a young friend of mine, who is now a settler in New Zealand, wrote describing to me certain woods in New Zealand which were practically non-flammable, and perfectly workable in ship construction. If the lecturer or anybody present is aware of their existence, there is an opportunity now of expressing their views, and giving us information.

Captain K. Yendo, Imperial Japanese Naval Attaché (Visitor): My Lord, I have nothing to say about this wood; but, as this paper refers to the late Japanese war, and to the fires which occurred on the Chinese and Japanese warships, I may say that the value of the non-flammable wood, if it can be made durable, would be very great indeed for use in men-of-war. I do not know for certain whether such wood is to be used in the Japanese ships building in the United States, referred to in this paper. As Mr. Cramp is here, perhaps he will tell us as to this matter. However, in future war I hope that this improvement in the scientific treatment of wood will entirely obviate fires on board ship.

Mr. J. J. Woodward (Member): My Lord and Gentlemen, the experience that I have had with non-flammable wood may perhaps be of interest to you; because, in the construction of three gunboats, built by the Newport News Shipbuilding Company, Virginia, in the United States, whose construction I have had the honour to inspect as the representative of the Navy Department, probably more of the wood used has been treated by a process which I think must be identical with that described by Mr. Ellis, than on any other vessels now built. The amount used on the three vessels in question was about 30,000 cubic feet. On beginning the use of the fire-proofed wood, to test its condition we arranged a small steel tube, containing a thermometer and having a large lamp capable of keeping the temperature of the tube uniformly at about 600° F., which was the contract requirement for the non-flammability of the wood. During the construction of the vessels, samples were taken from the wood treated by this process, and placed in the tube referred to, and the contract requirement was, in

all cases, fulfilled. In some of the hard yellow pine, which was particularly rich in resin, the treatment fulfilled the requirement of non-flammability at 600°, but there was a tendency to show a slight flame at higher temperatures, but it was extremely slight. In the softer woods the non-flammability was absolute. At the same time I thought it of interest, as two of the three vessels were of rather light scantlings, to make certain investigations as to the strength of the fire-proofed wood. A very careful series of experiments was made as to the tensile, bending, and crushing strength of untreated Oregon pine, and of Oregon pine treated by the fire-proofing process, and then kiln-dried. It is to be noticed that since the fire-proofing treatment requires the wood to pass through a cylinder where it is exposed to a solution in water, the wood becomes very heavily saturated, and it is practically necessary, in order to dry the wood so that it can be used within a reasonable time, to pass it through a drying kiln. As this was the first experience on any large scale that we have had with wood treated by this process, the time taken in passing it through the kiln was made as long as we felt necessary to get the very best results—about six weeks was taken—so that we could feel that we were using every possible precaution not to force the drying of the wood. With all those precautions we found that, with Oregon pine, the loss of strength was between 20 and 30 per cent. These figures are approximate; because, not knowing that a paper on this subject was to be read, I have no exact data available. I think, however, that that represents a fair average; it being noticed that the non-fireproofed air-dried wood is compared with the fire-proofed and kiln-dried wood. Of course, the kiln-drying itself tends to reduce the strength of the wood, apart from the fire-proofing. Naturally, this reduction in strength would tend to show that, when used on decks, the life of the decks treated by this process would be less. I think there are hardly enough data available —I certainly have not been able to obtain them—to predict with any certainty what the reduction in the life of the wood decks of the ship would be when this process has been used, but I think it cannot fail to be appreciable. Another point that arises, apart from the matter of working, which Mr. Taylor said has been met to a greater or a less extent—although, in working the decks in question, we have had a great deal of trouble and delay owing to the fact that it was necessary to change the design of the cutting tools for working the fire-proof material—is the fact that wood treated by this process absorbs moisture after it is thoroughly dry and worked into a ship much more rapidly than untreated seasoned wood would do. This gave rise to two difficulties. First, we found, when we began to run the mouldings for electric light wires on the ships, that the fireproofed wood, although it was as good a non-conductor as untreated wood when dry, yet, when pieces of the moulding were taken from the ship and tested, it was found that the fireproofed wood—taken from the ship and containing a certain amount of moisture—was in a very marked degree a better conductor of electricity than dry wood; so much so, that it was considered undesirable to use it for this purpose. Secondly, there was a good deal of trouble with the painting. The paint after being placed on the fireproof wood would peel off. Of course, if the ship were in an *absolutely* dry atmosphere, I do not think this trouble would arise. I understand it has never arisen in connection with any construction on shore. I think we all know that the conditions of shipyard work are such that it is practically impossible to paint all the surfaces of wood work before it is placed on the ship. It has to be fitted in its place on the ship. There must be unpainted surfaces which can absorb moisture when the joiner work is taken on board to be fitted in place, and any moisture that is then absorbed by the wood will affect the painting. To sum up, the difficulties that appear to present themselves in employing wood treated by this process can be met. Particularly with regard to the case of battens sheathing, &c., I think there can be no question as to the immediate value of wood treated by this process.

Mr. Arnold Hills (Associate): My Lord and Gentlemen, I should like to make a few remarks from my own personal experience on the paper which has been read by Mr. Ellis. Mr. R. Fox, who brought over this patent from America, came to see me at our works on the Thames, knowing we were interested in the matter, and I think we made the first experiment that was made in England with regard to the non-flammable character of wood. I can endorse all that Mr. Ellis has said in his paper as to the valuable properties due to this treatment, but I daresay that somebody here will be aware that a certain amount of combustion takes place in this treated wood. It becomes carbonised and charred, and if sufficient flame or heat is applied to the wood, even though it be treated with this process, it will perish or fail. I do not in the least want to detract from the value of the process. I believe, not only for naval architecture, but for many other purposes, such as house building, this wood has a great future before it, but there are two grave difficulties in its way. The first is the question of weight, which, so far as the naval architect is concerned, is of very great importance, and I suppose that is one reason why our Admiralty, who have been considering the subject, and the Japanese Admiralty also, who have had the matter before them, have not decided to adopt this process for their ships. But the more grave consideration is the probable cost of this wood. The information which I have received so far is that it will be from 30 to 50 per cent. dearer than ordinary wood when not treated. If this difficulty can be got over, I should think there would be an almost unlimited use for wood which has been so treated. There are a good many minds working on the subject at present, and I have received information from no less than three quarters in different countries dealing with this question of treating wood so as to make it non-flammable. I venture to think we shall find a very large development of the use of wood which has been so treated, not only in battleships, where the question of cost is not so important, but also large use will be made of it in buildings of every kind.

Professor J. H. Biles (Member of Council): My Lord and Gentlemen, I had the pleasure of seeing some experiments carried out in America upon this wood last year, and I think I may claim to have been the first in this country who received any specimens of wood treated in this way. I have also had the pleasure of seeing those experiments that were carried out in burning those two remarkable wood structures, and I think it is a great pity that those who are interested in the process could not have arranged to have given us an exhibition for the benefit of this Congress. I do not know whether it is too late yet to do anything in that way; but, if it could possibly be arranged, it would be of exceeding interest to all those who are present; because, while it is easy to say that this wood will not burn, and, no doubt, many have faith enough to believe what is told them, nevertheless, *seeing* the thing is so much better, and it would be of very great value to the Congress if some experiments could be carried out to enable the members to see the actual non-burning qualities of this wood. There are many practical applications of this in ships and also outside of ships. In ships it is perfectly obvious that it is of great advantage to have wood which is non-flammable—in warships particularly; but there is another quality which Mr. Ellis has referred to, and which may come to be of almost as great advantage, and that is the non-conducting quality of it for cool storage for refrigerating chambers in ships. This is rather a development which was not looked for when the process was first invented, but it may be, perhaps, of almost as much practical value as the non-burning qualities. A curious thing that happened in the firing of the house was that, a wooden box was filled with papers and placed in the midst of a pile of wood which became a tremendous fire, and when the fire had all burnt out, the wood box remained, a little charred, but nothing burnt in the inside of it, and thus it proved itself a

perfect safe for valuable property. It seems to me, if we could combine the subject of this paper with the subject of the last paper, and make a non-flammable safe with a Harveyed iron inside to it, you would get a fire-proof and a burglar-proof safe on very much cheaper lines than you can get it at present. One of the objections that has been raised to this wood seems to me to be limited in its scope. It has been said that it was probably not so successful as one could wish when applied to decks exposed to the water and to washing. It seems to me that that is a very small matter after all, because wooden decks are not a great proportion of the weight of a warship. I think it quite possible that even that difficulty, supposing it does exist, may be got over by covering the decks with a solution of the same chemicals with which the wood is impregnated. If, after washing the decks, they were then rubbed with a mop with some of the solution, there would be a tendency to absorb what had been washed out. I do not myself attach very much importance to that, because, even if you do get a little washed out, your decks are no worse off than they were when they were not treated. An eminent newspaper expert has, in criticising the fleet at Spithead, spoken of the application of this process to the cruiser *Brooklyn*, and he has ventured to prophesy that the decks of that steamer will not last through half of her commission. He has said that the Americans have developed a very good process, but that, in treating their decks with this, they have run up against the difficulty that this process makes the decks spongy, and causes them to wear out in the course of half a commission. I took the trouble to go down to the *Brooklyn*, and looked at her decks, and I found them in an exceedingly good condition. The decks were made of Oregon pine. The Oregon pine does not present quite the bright white appearance that Riga fir does when treated in men-of-war fashion, but it makes excellent decks. Therefore, I am not prepared to agree with the criticisms of this newspaper expert; and, further, I am not prepared to agree in his objections to this process as applied to this ship, because, on further questioning, I found that the decks of this steamer had not been treated by this process at all. The amount of influence that has been given by the press to the criticism of technical matters is, of course, great; but occasionally they do make little slips of that kind. With regard to the question of total weight of wood in a steamer, especially in a warship, I think that the additional weight that is put in by this process will really be so small throughout the whole of a ship that it cannot possibly be compared with the enormous advantage of having wood which is non-flammable. I think Mr. Ellis would interest the meeting if he would give some idea of the extra cost that is really involved in adopting this process.

Mr. Robert Thompson (Member): Perhaps Mr. Ellis will be good enough to tell us the length of time required to put the wood through this process.

Mr. C. Ellis (Associate): My Lord and Gentlemen, very few remarks are necessary from me in response to the criticisms which have been passed upon this paper. I think, as a matter of fact, most of those criticisms have already been answered by the fact that this wood has been practically adopted by two of the most important naval Governments of the world; and if there were any serious objections on the ground of the strength of the wood, or on the ground of difficulty of manipulating it—if those objections were really serious—it almost goes without saying that those important Governments would not have so largely adopted the use of the wood as has been the case. With regard to the strength of the wood, which was alluded to by Mr. Woodward most particularly, I understand that, in private trials held in this country, exactly the reverse has been proved to that stated by Mr. Woodward, and it has been found that the treated wood was considerably better in point of strength than non-treated wood of the same kind. The question of the increase of weight which was alluded to—the increase of weight from 8 to 15 per cent.—is also answered by the

practical considerations I have mentioned, namely, that the Governments have decided to use it, and therefore the increase of weight cannot be of so very much importance. Of course, we all know difficulties, particularly in new inventions, seem to exist simply for the express purpose of enabling people to get over them; and I have not the slightest doubt, with regard to this invention, as with every other invention that people have to deal with, difficulties are raised and eventually got over. To my mind the most important note in this discussion was struck by Mr. Hills when he referred to the question of cost. I think with him, unless the cost is reasonable the use of the wood will be very much less than otherwise would be the case. No doubt it will be for those who are commercially responsible for the introduction of this wood to see that the cost, which it is proposed to put on for the treatment of the wood, is not so unreasonable that it will prevent its large adoption in battleships and other vessels in our marine. With regard to Admiral Boys' question as to some particular wood in New Zealand, I am sorry I have not any information with regard to that. I have not heard of any such wood; but, if I do hear of anything, I shall be very glad to acquaint him with the result of any inquiries I can make. One more question was asked, with regard to the length of time that it took to treat this wood. I believe it takes from about thirty to forty hours. I think, my Lord, that is all I have to say.

Mr. J. R. Oldham (Visitor): My Lord, I am pleased to be assured that the process referred to does not destroy the strength or preservative qualities of the wood. I am afraid, however, that its extra weight—some 10 to 15 per cent.—would severely militate against its general adoption in war vessels, though for the mercantile marine there would be little objection on that score, as metal is not likely to supersede wood for state-room bulkheads, sleeping berths, doors, &c., for these were tried in the two large steamers *Montana* and *Dakota* many years ago, and turned out to be signal failures.

Professor J. H. Biles: I should like to say, my Lord, that the chairman of the company who is responsible for this wood has authorised me to state that he will be very pleased to see any members at five o'clock on Thursday afternoon at Hurlingham, when he will give a demonstration of the non-flammable quality of this wood.

The President (the Right Hon. the Earl of Hopetoun, G.C.M.G.): Gentlemen, I am quite certain that you will all desire to accord a very hearty vote of thanks to Mr. Ellis for his most interesting paper.

A REVIEW OF THE HISTORY AND PROGRESS OF MARINE ENGINEERING IN THE ROYAL NAVY AND MERCANTILE MARINE FROM THE FOUNDATION OF THE INSTITUTION OF NAVAL ARCHITECTS TO THE PRESENT DATE.

By Sir JOHN DURSTON, K.C.B., R.N., Engineer-in-Chief of H.M. Navy, Vice-President; and J. T. MILTON, Esq., Chief Engineer Surveyor of Lloyd's Register of Shipping, Member of Council.

[Read at the International Congress of Naval Architects and Marine Engineers, at the Imperial Institute, July 6, 1897; Sir EDWARD REED, K.C.B., F.R.S., Vice-President, in the Chair.]

So much has been written on this subject, and the nature of the progress made, particularly in recent years, is a matter of such common knowledge in the engineering and shipbuilding world, that it will not be possible in this paper to present any original facts to the Institution.

The writers can only hope, by confining the view to the years covered by the title of the paper, to accentuate some of the most important features of the history and progress, and the causes which have made them possible.

In dealing with the subject it will be necessary to divide it broadly into two parts:

(1) A consideration of the progress made in the theoretical knowledge of the principles affecting the design and working of the machinery.

(2) The progress made in carrying out these principles in practice, and actually obtaining, in satisfactory working arrangements, the increased efficiency and advantages which theory has led us to expect.

In 1859, the year previous to that in which this Institution was founded, there appeared the first edition of that valuable work on the steam engine by J. Macquorn Rankine, who was from the first a prominent and valued member of the Institution. This work was the product of a master mind, and may be taken as representing what was most advanced in the science of engineering at that time. Subsequent works have contained new and extensive details of the many improvements since made in the design and construction of marine engines and boilers, but have added comparatively little to the theoretical knowledge set forth in that work.

Rankine, Hirn, Cotterill, and others, have, by the tables of properties of steam and the deductions therefrom, which they have published, clearly set forth the increases of economy which might be expected from the use of higher pressures of steam. Such tables and deductions have been valuable incentives to progress, but the advantages they foreshadowed have only been realised by constant effort and experiment in the practical engineering world.

There is one important principle which was apparently not recognised by engineers in 1859, and it is certainly not stated in Rankine's work of that date—*i.e.*, the diminution of liquefaction and its attendant losses, and the gain in economy obtained, by carrying out a given range of expansion in two or more successive stages in separate cylinders rather than in one; and, as far as the theory of the steam-engine is concerned, the progress during the years of this Institution may be considered to consist chiefly in the knowledge which has been gained by experiment and practical experience on these points.

Turning, however, to the second part of the subject, we find considerable advance; and it is in putting into practice and realising, in successful working machinery at sea, the advantages of increased pressure and expansion of steam, that the great progress during the period covered by this paper has been made. Engines and boilers in the Royal Navy and Mercantile Marine are now working as satisfactorily, and at least twice as economically, at 180 lbs. to 250 lbs. pressure as they did at 20 lbs., which may be taken as the pressure in general use in 1860.

Much of this progress has been due to men who have occupied prominent places as members of this Institution, and, in considering such a subject as this at such a time, we may well recall, with satisfaction and respect, the names of Joseph Maudslay, John Penn, sen., the Napiers, Scott Russell, Kirk, Sennett, and others, besides names the mention of which is only prevented by their presence with us to-day, who have been so intimately associated with definite progress, and who have, from time to time, favoured this Institution with the earliest reports of their efforts, and received from it that sympathy and impetus of thought which have urged them to further advances.

Remembering that the machinery in general use in steamships in 1860 was the simple engine with jet condensers, box boilers, and about 20 lbs. pressure, the practical advances during the period covered by this paper may be summed up as follow:—

Permanent introduction of the surface condenser (after having been tried and dropped), and the general rise of pressure made possible by its adoption.

Adoption of the circular or Scotch form of boiler, and consequent further rise of pressure.

The successful reintroduction of the compound engine, which had been previously tried and abandoned.

The adoption of twin-screws in the Royal Navy, and later in the high speed vessels of the Mercantile Marine.

Steady rise of pressure to limit of economy obtainable in practice with the compound engine.

Introduction of the triple-expansion engine, and consequent further rise of pressure to the limit practicable with the circular boiler, and combined with this rise of pressure the adoption, in some cases, in the Mercantile Marine of the quadruple expansion engine.

The adoption of water-tube boilers in the Royal Navy generally, and in a few cases in the Mercantile Marine.

Extending over the whole period there has been a steady rise of piston speed and speed of revolution, and considerable improvement in design generally, in the distribution of steam, and in the balancing of working parts. There has also been a steady reduction in weight of the machinery and boilers generally, and particularly of the moving parts, due to these causes, and also to the employment of improved materials of construction, and to the more correct determination of stresses, and arrangement of material to meet them.

The balancing of engines is at present coming very much to the front in the torpedo-boat destroyers, where the high speed of revolution, and lightness of hull, make it necessary to diminish the vibratory forces as much as possible.

It is questionable whether any similar period can show a list of solid progress to, in any way, approach that given above.

These advances have only been made possible by many improvements in detail, among which may be mentioned the following:—

The invention of the Siemens air furnace, and with it the production of mild steel suitable for plates and forgings, in large quantities and in large masses, and of uniformly reliable quality.

The production of the corrugated and other similar forms of furnace for boilers.

The invention and perfection of the various forms of evaporators and double distillers as a means of supplying fresh water for boilers.

The production of high-class steel and iron tubing, chiefly of the seamless type, for boiler tubes and steam pipes.

The invention and perfection of various forms of metallic packing, asbestos packed cocks, and other contrivances for dealing with the higher pressures of steam.

A general improvement in machine and other tools, and the introduction of new forms, such as hydraulic forging presses, riveters, and flanging machines, milling machines, gas and electric welding plants; the multiplication of Whitworth gauges, and the more general use of these and of taps and die nuts for producing well-fitting screw threads. All these have facilitated the rapid and certain production of high-class work, for which our leading engineers have always been noted, and which is at the basis of all true progress, and much of the credit of the general progress which has been made is due to those who have been associated with these details.

The mention also of the example and practice of the locomotive engineers must not be omitted, who, until they reached the limits which they considered sufficient for their requirements, were well in advance of the rest of the engineering world as regards both pressure of steam and piston speed; and it is due to them to say that, in the earlier efforts in the Royal Navy to obtain the maximum of power, on minimum weight, and in the space allowable in small vessels of high speed, it was by following the lead of locomotive practice in some important directions that the desired results were obtained. In the matter of pressure and piston speed, the locomotive practice is now behind that of the Royal Navy.

The advances in the Royal Navy and Mercantile Marine have run side by side, except perhaps in the three following, which are peculiar to the Royal Navy:—

(1) The increased working pressures and diminished test pressures allowed on boiler shells, and the consequent advantage of a considerable reduction in the weight of the same.

(2) The general adoption of the water-tube boiler.

(3) The adoption of the closed stokehold system of forced draught, combined with the use of the Admiralty pattern ferrule as a means of obtaining a high power on a given weight for a short time in cases of emergency.

In the Mercantile Marine forced draught is used in many cases, but it is generally the closed ashpit system which is applied.

It is considered that, in the Royal Navy, these steps have now all been justified by experience, and the satisfactory condition of the machinery in many of our warships to-day is associated with their adoption. They have secured to us distinct advantages which have materially contributed to the fighting efficiency of our vessels. The Mercantile Marine have not, apparently, up to the present required the assistance of these advances, and it is in the difference in the requirements of the two spheres that we must look for the explanation of the differences in practice.

A study of the Transactions of this Institution, viewed in the light of what has now been accomplished, shows how practical and sound were the ideas of some of its earlier members. Ideas which were then only prevented from being realised in practice by death, or by less favourable surroundings than inherited by the present generation.

In 1865, in the discussion on a paper reporting the failure of compound engines and surface condensers, we find the following significant remark by Mr. Scott Russell: "I myself continue to hope that the engines of the future are to be high-pressure expansive engines working with surface condensers and fresh water in their boilers."

In a discussion in 1868, the following occurs :—

"Everything which can conduce to the employment of high-pressure steam used expansively is by far the most practical operation to which to direct our thoughts. By employing high-pressure steam ocean navigation may be extended much more to the advantage of the country than it is now." If time allowed, many similar quotations could be made from the valuable papers and discussions on compound and triple-expansion engines, the use of steel, and the valuable contributions on the screw-propeller by the late Mr. Froude.

A few remarks on the progress of the water-tube boiler may perhaps not be out of place at this stage.

Water-tube boilers working at 120 lbs. pressure were fitted in the S.S. *Thetis*, on the Clyde, in 1857, and many forms were developed and tried in this country for marine purposes between that date and the year 1879, notable cases being the Rowan, Howard, Root, and Perkins types.

These boilers, although they were in general appearance similar to the modern types, were not a success, their chief defects being deficient circulation, and inaccessibility for cleaning and repairs. The Dundonald boiler, in its modified form known as the Cochrane, which had water tubes, was tried in the Royal Navy (1867-70), in the *Chanticleer*, *Oberon*, *Audacious*, and *Penelope*, and in the S.S. *Spartan*, in 1875, but troubles with priming and difficulties of cleaning caused it to be abandoned. In 1874 and 1875 the failure of the boilers of the *Propontis*, *Montana*, and other vessels of the Mercantile Marine fitted with water-tube boilers, was marked, and was attended in some cases with loss of life. These failures, combined with the fact that sufficiently high pressures for the engines then in use could be satisfactorily obtained from other types of boiler, caused water-tube boilers to be completely dropped, in this country, just at the time when other forms were being successfully taken up by our neighbours and guests, the French.

Coming to the present revival of water-tube boilers in this country, the first successful case appears to have been that of the mission vessel *Peace*, which

was fitted with a water-tube boiler by Messrs. Thornycroft, in 1882. Following this, water-tube boilers were fitted to the *Ariete* by the same firm, who also fitted a water-tube boiler to a second-class torpedo-boat in the Royal Navy in 1885. Another second-class torpedo-boat was fitted with a water-tube boiler by Yarrow, in 1892. As far as the Royal Navy is concerned, the boilers of these two boats were the first successful water-tube boilers, and the firms who produced them stood alone, for some time in this country, as makers of efficient water-tube boilers for ships. Since then the boilers of Thornycroft and Yarrow, and the French boilers of Normand and Du Temple, with the later English boilers of Reed and Blechynden, have all been fitted to vessels in the Royal Navy, and are answering well. The above are all small-tube boilers. Most of the credit of producing satisfactory boilers of the large-tube type suitable for ships is due to our neighbours, the French, who have successfully fitted them since 1871 in their Mercantile Marine, and since 1879 in their ships of war. The most interesting case of persistent effort in this direction is that of the Belleville, the patents in connection with which date from 1850.

Apart from the question of the merits of the French boilers, it is only due to Messrs. Belleville, Du Temple, Normand, and other French engineers, that this paper should acknowledge the value to the engineering world of the efforts they have made to overcome the difficulties connected with the water-tube boiler.

With reference to other elements of progress, we may mention the introduction and improvement of Parson's turbomotor, and the recent remarkable results which have been obtained in a boat fitted with this engine. The use of liquid fuel has been constantly kept in view by the Institution: papers on this subject occur very early in the Transactions by Captain Selwyn and others. The question is affected largely by the supply of fuel which is available, and, as far as the Royal Navy is concerned, by other points peculiar to warship design. A torpedo-boat destroyer in the Royal Navy is now being fitted with means for burning liquid fuel in one of its two stokeholds, and will shortly be tried.

Plates IV. to VII. at the end of the paper have been constructed to show graphically the rises in pressure of steam, piston speed, total indicated horse-power, and speed of revolution, which have taken place in the Royal Navy between the years 1860 and 1897.

In Plate IV. the total indicated horse-power of all the effective ships has been set up to scale at the years given, and a curve has been drawn through the points so obtained. The indicated horse-power under construction is shown for the later years by setting it up from the first curve, and the second curve, so obtained, thus represents the total indicated horse-power, including that under construction.

In Plate V. the rise of pressure in the Royal Navy is graphically traced. The upper dotted line represents the advanced guard of smaller ships, and the lines have been carried back before 1860 to show where the divergence commenced. It is interesting to notice that the advanced guard has now been outstripped by the main body; the *Terrible* and the *Pelorus* having pressures of 260 and 300 lbs. respectively, against 250 lbs., the highest in a completed torpedo-boat destroyer. There have been jumps of pressure at various times, notable cases being the *Lightning*, the first torpedo-boat built for the Royal Navy, the *Herreschoff* torpedo-boat, and other torpedo-boats by Thornycroft and Yarrow.

The straight line at 1889 to 1897 indicates that the limit of pressure considered desirable with the tank boiler (under the conditions of weight and space allowable in the warships of the Royal Navy) had been practically reached; the further rises of pressures after this date have been made by the adoption of the water-tube boiler, and the lines are made thick where the steam is obtained from water-tube boilers.

It may be remarked here with reference to the rise of pressure that, as the pressure has increased, so the difficulty in making a further rise has diminished, and a rise of from 150 lbs. to 250 lbs. has been made with less difficulty, and certainly with less risk and less proportion of actual failures, than the rise from 30 lbs. to 60 lbs. in the earlier stages of progress. After all, the rise of temperature in recent advances is comparatively small.

Plate VI. shows the piston speeds which have obtained in the Royal Navy since 1860.

A line has been drawn connecting the lowest examples, and it will be seen that there has been a steady general rise. By comparing the highest and lowest cases, *i.e.*, the *Warrior*, with a speed of 434 ft. per minute, and *Starfish*, with a speed of 1,221 ft. per minute, it will be seen that the piston speed has been practically trebled.

Increased speed of revolution has been a most important factor in diminishing the size and weight of the engines, and in Plate VII. these increases are indicated. The speed of revolution naturally varies with the speed, size, and draught of water of the vessel, and also the size of the engines.

In the figure, the vessels have been arranged in classes following very closely their official classification; representative ships are selected and a line passed through them, special cases being shown by isolated spots. The lower line shows the battleships, and the *Bellerophon* and *Hercules* are notable cases of high speed of revolution for the time in which they were constructed, and in view of the size of the engines, the *Bellerophon* being 6,500 I.H.P., and the *Hercules* 8,500 I.H.P.

The lines —· —· on diagram refer to the cruisers, which practically commenced with the *Inconstant* and the *Volage* in 1869. The earlier cruisers existed without much attempt at classification; later we find divergencies which eventually become accentuated into first, second, and third classes as shown by the three lines —· —· on diagram.

Vertical engines were fitted in the first-class battleships in 1875, and about 1887 the horizontal engine was abandoned generally for the vertical, the change being made practicable by modifications in the ship design, chiefly as regards protection. The stroke of the vertical engines was greater than that of the horizontal engines they replaced, and the revolutions were therefore less, though there was a slight increase in piston speed.

An interesting illustration of this is given by comparing the *Orlando* and the *Hawke*. We have in the *Hawke* an increase in piston speed to 870 from 830 in the *Orlando*, but a decrease in speed of revolution from 119 in the *Orlando* to 102, due to the employment of a 4 ft. 3 in. stroke, as against the 3 ft. 6 in. stroke of the *Orlando*. The result has been a much smoother running and more economical if somewhat heavier engine. Most of the *Hawke* class have made long runs at high speeds, in some cases over 18 knots, with a coal consumption of 1·6 to 1·7 lb. of coal per indicated horse-power.

In the early torpedo gunboats there was a sudden and considerable increase of speed of revolution, but they soon evolved into two classes, the slower running *Halcyon* class, and the torpedo-boat destroyers, which are shown by the upper spots.

A comparison of one of the twin engines of the *Mars* and the single engines of the *Warrior* shows that the speed of revolution has been practically doubled in battleships for engines of the same power.

In Table I. there are given a few particulars of representative ships in the Royal Navy, which embodied the advanced practice at the time they were designed. Some torpedo-boat destroyers are added, as the machinery of these little vessels represents, with the single exception of the steam pressure employed, what is most advanced in modern marine engineering.

The *Warrior* was launched in 1860 and tried in 1861. She has been since reboilered, but the original engines are still efficient. Besides the general features already mentioned, we find in her machinery many now obsolete details, such as dead-weight loaded safety valves, feed and bilge pumps worked off the main engines, cast iron condensers; while the engines are started and turned by hand gear, and, as first fitted, there was no steering engine. There is also an entire absence of steel in the construction of engines and boilers.

Passing over a period of eleven years to the *Devastation*, we find the engines are still simple, but twin screws have been adopted, surface condensers are fitted instead of

jet, and the number of auxiliary engines is doubled, and includes steam-engines for steering, and for working the gun machinery and ventilating the ship. The next six years bring us to the *Inflexible*, in which the horizontal simple engine is replaced by the vertical compound. The auxiliary engines are increased fivefold, including hydraulic pumping engines and a variety of hydraulic motors driven by them for working the gun machinery. Steam-driven ventilating fans are freely used. The box boiler has disappeared, and its place is taken by oval boilers, some of which are double-ended. The engines are also fitted with piston valves. The expansion valve disappears at this stage, the *Inflexible* having been so fitted originally, but the valves were removed soon after her trials.

We find another very important advance in this ship, the prelude of a revolution in shafting; for, while her crank shafts and connecting and piston rods are iron, the propeller shafting is of Whitworth compressed steel and hollow. As illustrating the advance which has been made in the matter of boiler preservation, it may be noticed that the *Inflexible's* boilers are still efficient.

An interval of ten years from the *Inflexible*, brings us to the *Sanspareil*, and the advances here are again very marked. The compound engine is replaced by the triple-expansion. Steel replaces iron generally for shafts, rods, columns, and also for the main bearing frames, and the crank and propeller shafts are hollow throughout. The boiler pressure is more than doubled. The boilers are entirely of steel with corrugated furnaces. The piston speed is increased nearly 50 per cent. Cast iron pistons are replaced by cast steel in the case of the low pressure and intermediate pressure pistons, and arrangements for forced draught are fitted. The number of auxiliary engines has increased to 92, and their indicated horse-power to 2,100. The feed-pumps are no longer worked off the main engine, evaporators are fitted for making up loss of fresh water, and in the construction of the condenser cast iron is replaced by gun-metal.

The advances of the nine years succeeding the *Sanspareil* are best seen by comparing that ship with the *Terrible*.

The boiler pressure in the *Terrible* is nearly double that in the *Sanspareil;* and, although the figures in line marked * do not indicate any reduction in weight, it must be remembered that, while the *Sanspareil's* power was obtained by a liberal use of forced draught, the *Terrible's* was obtained without any air pressure, the stokeholds being open, and by comparing the *Terrible* with the *Sanspareil* under the same conditions as in line marked †, we have a reduction in weight per indicated horse-power in favour of the *Terrible* of over 35 per cent. The reduction in weight from the *Prince George* is seen from the table, but in this ship again the maximum power was obtained with forced draught. Taking the natural draught power of the *Prince George*, as at †, there is again a reduction of weight in favour of the *Terrible* of 33 per cent. In the *Terrible*

TABLE I.

Ship.	Date of Trial of Machinery.	Maker of Engines.	Details of Engines.					Number of Revolutions.	Piston Speed.	I.H.P.	Air Pressure in Stokeholds. Inches.	Boiler Pressure. Lbs. per Sq. In.	Description of Boiler.
			Screw.	Type.	Number of Cylinders.	Diameter in Inches.	Stroke in Ft. In.						
Warrior ..	Oct., 1861	J. Penn & Son	Single	Jet condensing, simple horizontal, trunk	2	112	4 0	54·25	434	5,469	Nil	22	Rectangular iron
Devastation..	Oct., 1872	,,	Twin	Surface, simple horizontal, trunk	4 (2 to each engine)	80	3 3	76·92	500	6,652	,,	30	
Inflexible ..	Nov., 1878	J. Elder & Co.	,,	Surface, compound, vertical.	6 (3 to each engine)	2 of 70 4 of 90	4 0	73·26	586	8,483	,,	61	Oval, single and double-ended, iron
Sanspareil ..	Sept., 1888	Humphrys, Tennant & Co.	,,	Surface, triple expansion, vertical	6 (3 to each engine)	2 of 43 2 of 62 2 of 96	4 3	100·73	856	14,483	2	135	Circular, single-ended, steel.
Prince George	Sept., 1896	,,	,,	,,	6 (3 to each engine)	2 of 40 2 of 59 2 of 88	4 3	101·8	865	12,280	1·25	155	,,
Terrible ..	Jan., 1897	J. & G. Thompson	,,	,,	8 (4 to each engine)	2 of 45 2 of 70 4 of 76	4 0	112·0	896	25,648	Nil	260	Belleville water-tube
Ferret	Oct., 1894	Laird Bros.	,,	,,	6 3 to each engine)	2 of 19 2 of 29 2 of 43	1 6	60·08	1080·24	4,474	4·1	175	Normand water-tube
Janus	Nov., 1895	Palmers	,,	,,	6 (3 to each engine)	2 of 18 2 of 27½ 2 of 42	1 6	367·1	1101·3	3,789	2·48	210	Reed's water-tube
Desperate ..	Sept., 1896	Thornycroft	,,	,,	8 (4 to each engine)	2 of 20 2 of 29 4 of 30	1 6	397·6	1193·8	5,796	3·5	215	Thorny-croft's water-tube
Quail	Jan., 1897	Laird Bros.	,,	,,	6 (3 to each engine)	2 of 21 2 of 32½ 2 of 48	1 6	367·2	1101·6	6,057	4·77	220	Normand water-tube

TABLE I.—(*Continued.*)

Ship.	Number of		Approximat. I.H.P. of all Auxiliary Engines.	Weight of					I.H.P. per ton of			Coal per I.H.P.
	Boilers.	Auxiliary Engines.		Machinery and Boilers, with Water at Working Height.	Engines, Main and Auxiliary.	Boilers with Water at Working Height.	Water in Boilers at Working Height.	Water in one Boiler at Working Height.	Engines.	Boilers.	Water in Boilers.	
				Tons.	Tons.	Tons.	Tons.	Tons.				lbs.
Warrior ..	10	8	350	898·2	421·63	476·6	171·7	17·17	12·97	11·47	31·87	3¾ to 5
Devastation ..	8	16	880	971·95	484·2	487·7	125·8	19·1	13·73	13·64	52·87	3·12 to 4·42
Inflexible ..	12	82	1,420	1366·4	654·2	712·2	187·38	18·56	12·96	11·9	45·27	2·38 to 2·74
Sanspareil ..	8	92	2,100	1089·36	509·19	581·1	132	18·8	*28·44 †15·85	*24·96 †13·87	*109 †61·14	1·88 to 2·6 (according to speed and quality of coal)
Prince George	8	146	2,800	1326·59	623·8	702·7	165·2	20·65	*19·7 †16·77	*17·33 †14·89	*74·33 †63·34	1·82 on 30 hours' trial at 50 per cent. of full power.
Terrible ..	48	89	2,900	2224·78	1076·4	1148·3	48·75	1·06	23·8	22·3	526·1	1·71 on 30 hours' trial at 74 per cent. of full power.
Ferret	4	19	150	123·61	59·4	64·1	11·48	2·87	75·2	69·7	389·7	2·3 at 11 knots
Janus	4	20	170	120·0	49·0	70·69	7·95	1·99	77·3	53·6	477·0	2·5 at 13 knots
Desperate ..	3	18	230	127·95	61·49	66·46	7·75	2·58	94·3	87·2	747·0	2·5 at full speed 1·67 at low speed
Quail	4	17	230	144·3	68·6	75·7	11·25	2·81	88·4	80·1	539·0	2·64 at full speed 1·64 at low speed

NOTE.—The figures for indicated horse-power per ton given at * are based on the forced draught power, those at † on the natural draught power.

we have, besides water-tube boilers, many improvements in detail necessary in order to deal with the high pressures with certainty. Among these may be mentioned a general use of steel steam pipes, and of metal to metal joints, also of asbestos-packed cocks and metallic packings. There are also improvements for dealing with the water from the air-pumps, and for extracting grease from the same, and a large increase of capacity in the plant for supplying fresh water.

One of the most important features is the large reduction in the weight of water carried in one boiler—a matter of considerable moment in case of damage in action or failure of any part when under steam. The small amount of total water carried in the boilers is also noticeable, making it, with the arrangements supplied to the *Terrible*, an easy matter to run the boilers always with distilled water if desired.

A comparison of the torpedo-boat destroyer *Quail* with the *Warrior* suggests itself on account of the indicated horse-power of the two vessels being so nearly the same, and because of their positions at the beginning and end of the period under consideration. The weight of the *Warrior's* machinery, only, would more than supply two complete *Quails*, hull and machinery, with crew and stores equipped for sea. While, if the weight of the *Warrior's* machinery were turned into machinery of the *Quail* class, it would supply 38,000 I.H.P. instead of 5,400, with a coal consumption per indicated horse-power of half that of the *Warrior*.

In the Mercantile Marine the advance of engineering has been steady and continuous. In the majority of cases economy of coal has been, as it always will be, the predominating factor affecting the design, and the progress made in this direction has, no doubt, been the principal reason of the great development in steam shipping, both in point of numbers and in size of vessels engaged in general commerce, while it has rendered it possible for them to compete in trades previously monopolised by sailing vessels.

Table II. shows the increase in the number of British and Colonial steam vessels in each decade since the foundation of the Institution. It shows also the gradual increase in the powers of the individual vessels which have rendered possible the attainment of speeds at sea which a few years ago would have been considered to be impracticable.

Appended also in Tables III. and IV. are the particulars of the fleets of the Cunard and the P. & O. Companies for the years mentioned in Table II. These may be taken as representative of the vessels of the other great lines, and, so far as types of engines, &c., are concerned, they are representative of the then best practice in the marine engineering world. These particulars show the gradual rise of steam pressure, the increase of size and power of engines, and of piston speeds, and the advancement made as regards economy of coal consumption.

In concluding the paper it may not be out of place to remind ourselves how much of the great progress in marine engineering of the past thirty-seven years has been due to the cordial relations which have existed between the various nations represented at this gathering, and the increased facilities for intercommunication which have enabled each to be assisted by the advances of the other; and we may, on such an occasion as this, reflect with satisfaction on the fact that these relations and intercommunications, by assisting so materially in the progress of marine engineering, have conduced very much to the general prosperity and happiness of the Western world, to which that progress is so closely allied.

TABLE II.

SHOWING INCREASE IN NUMBER OF BRITISH AND COLONIAL MERCANTILE STEAM VESSELS.

	1860.	1870.	1880.	1890.	1897.
No. of Steam Vessels registered as 100 tons and above	931	1,727	3,974	6,403	7,534
No. of Steam Vessels registered as 100 N.H.P. and above	650	1,040	2,208	3,707	4,469
,, ,, ,, 400 ,, ,,	86	107	235	444	626
,, ,, ,, 1,000 ,, ,,	2	1	5	36	53
No. of Steam Vessels having speed of 20 kts. and above	—	—	—	8	22
,, ,, ,, ,, 19 to 20 kts. ,,	—	—	—	8	23
,, ,, ,, ,, 18 to 19 ,,	—	—	6	14	39
,, ,, ,, ,, 17 to 18 ,,	—	1	7	27	41
,, ,, ,, ,, 16 to 17 ,,	—	1	8	27	47
,, ,, ,, ,, 15 to 16 ,,	1	6	20	62	88

TABLE IIIa.

The Cunard Fleet in 1860.

Name of Ship.	Description of Engines.	Cylinders. Diameter. Inches.	Cylinders. Stroke. Inches.	Boiler Pressure. Lbs.	Piston Speed. Ft. per Min.	I.H.P.	Coal. Tons per Day.	Coal. Lbs. per I.H.P. per hour.
Cambria	Side lever	77½	90	10	256	1,040	44	4·0
America	,,	88¾	96	18	224	1,600	58	3·38
Niagara								
Europa	,,	90	96	18	224	1,850	67½	3·41
Canada								
Asia	,,	96⅝	108	18	261	2,160	74	3·2
Africa								
Arabia	,,	103	108	18	270	3,000	105	3·2
Persia	,,	100½	120	24	320	4,180	157	3·5
Satellite (tender)	1-cylin., side lever	50	42	12	—	—	—	—
Delta...	Beam, geared	42	38½	16	218	—	28	—
Etna	,,	76¾	63	14	325	—	50	—
Jura	,,	76	65¼	14	272	1,350	48½	3·35
Melita	Oscillating, geared	50¼	54	13	252	612	22¼	3·38
Palestine	,,	57	57	16	237	—	30	—
British Queen	Vertical, direct	48	33	12	330	500	20	3 73
Balbec								
Karnak								
Stromboli	,,	42½	31	17	284	—	19	—
Damascus...	,,	52	36	14	270	680	27	3·7
Australasian	,,	90	42	20	294	3,070	100	3·0

TABLE IIIb.—The Cunard Fleet in 1870.

Name of Ship.	Description of Engines.	Cylinders		Boiler Pressure. Lbs.	Piston Speed. Ft. per Min.	I.H.P.	Coal. Tons per Day.	Consl. Lbs. per I.H.P. per hour
		Diameter. Inches.	Stroke. Inches.					
Satellite (tender)	1-cylin., side lever	50	42	12	—	—	—	—
Palestine	Oscillating, geared	57	57	—	—	—	30	—
British Queen	Vertical, direct	48	33	14	330	500	20	3·73
Balbec	Vertical, direct	48	33	—	—	500	20	—
Stromboli	,,	42½	31	20	315	—	19	—
Atlas	Oscillating, geared	58	60	20	260	860	37	4·0
Olympus	Oscillating, geared	58	60	20	260	860	37	4·0
Hecla	,,	59¼	60	20	285	930	38	3·8
Marathon	,,	59¼	60	20	285	930	38	3·8
Sidon	,,	58	60	21	260	860	37	4·0
Kedar	,,	58	60	21	260	860	37	4·0
Morocco	,,	58	60	21	260	860	37	4·0
Scotia	Side lever	100	144	25	384	4,200	164	3·6
China	Oscillating, geared	80	66	22	308	2,000	80	3·7
Corsica	,,	51	54	21	216	680	25	3·4
Cuba	,,	82	72	22	300	2,300	83	3·36
Tripoli	,,	61½	60	24	250	1,100	40	3·40
Malta	,,	61½	60	24	250	1,100	40	3·40
Tarifa	,,	61	60	23	250	1,100	40	3·4
Aleppo	,,	61	60	23	250	1,100	40	3·4
Palmyra	,,	61	60	23	250	1,100	40	3·4
Java	Vertical, direct	85	42	25	378	2,440	85	3·25
Russia	,,	86	45	25	412	2,900	98	3·15
Siberia	,,	61	42	25	371	1,400	48	3·2
Samaria	,,	61	42	25	371	1,400	48	3·2
Calabria	,	72	48	30	432	2,480	86	3·2
Abyssinia	,	72	48	30	416	2,480	86	3·2
Algeria	,	72	48	30	408	2,480	86	3·2
Batavia	Compound	51 and 86	48	60	400	1,700	41	2·25
Parthia	,,	56 and 97	48	60	408	1,870	45	2·25

TABLE IIIc.

The Cunard Fleet in 1880.

Name of Ship.	Description of Engines.	Cylinders.		Boiler Pressure. Lbs.	Piston Speed. Ft. per Min.	I.H.P.	Coal. Tons per Day.	Coal. Lbs. per I.H.P. per hour.
		Diameter. Inches.	Stroke. Inches.					
Satellite (tender)	1-cylin., side lever	50	42	—	—	—	—	—
British Queen	Compound	29 and 54	36	65	360	580	14	2·25
Balbec	,,	28 and 56	36	65	360	510	13	2·38
Atlas	,,	44 and 78	42	66	392	1,150	28	2·27
Olympus								
Hecla	,,	44 and 78	42	66	392	1,150	28	2·27
Marathon								
Sidon...	,,	39 and 68	45	60	405	850	23½	2·57
Kedar								
Morocco								
China	,,	51 and 86	48	63	—	1,750	43	2·3
Malta	,,	38 and 68	48	70	424	1,100	26	2·2
Tarifa	,,	38 and 68	48	70	424	1,100	26	2·2
Aleppo								
Palmyra								
Samaria	,,	45 and 80	42	70	392	1,600	39	2·27
Abyssinia	Vertical, direct	72	48	30	416	2,480	86	3·2
Algeria								
Batavia	Compound	51 and 86	48	60	400	1,700	41	2·25
Parthia	,,	56 and 97	48	60	408	1,870	45	2·25
Trinidad	,,	39 and 69¾	45	70	390	900	24	2·5
Demerara								
Saragossa	,,	40 and 71	45	67	405	1,000	27	2·5
Nantes	,,	33½ and 58½	42	65	357	600	16	2·5
Bothnia	,,	60 and 104	54	67	513	3,300	76	2·15
Scythia								
Cherbourg	,,	33½ and 58½	42	61	357	600	16	2·5
Gallia	,,	64, 80, 80	60	75	550	4,500	100	2·07

TABLE IIID.

THE CUNARD FLEET IN 1897.

Name of Ship.	Description of Engines.	Cylinders. Diameter. Inches.	Cylinders. Stroke. Inches.	Boiler Pressure. Lbs.	Piston Speed. Ft. per Min.	I.H.P.	Coal. Tons per Day.	Coal. Lbs. per I.H.P. per hour.
Satellite	1-cylin., side lever	50	42	—	—	—	—	—
British Queen	Compound	29 and 54	36	65	360	580	14	2·25
Marathon	,,	44 and 78	42	66	392	1,150	28	2·27
Kedar	,,	39 and 68	45	60	405	850	23½	2·5
Tarifa	,,	38 and 68	48	70	424	1,100	26	2·2
Aleppo	Triple-expansion	24¼, 35¾, 58½	48	160	536	1,250	18	1·34
Samaria	Compound	45 and 80	42	70	392	1,600	39	2·27
Trinidad	,,	39 and 69¾	45	70	390	900	24	2·5
Saragossa	,,	40 and 71	45	67	405	1,000	27	2·5
Cherbourg	,,	33½ and 58½	42	61	357	600	16	2·5
Bothnia ... ... / Scythia	,,	60 and 104	54	67	513	3,300	76	2·15
Gallia	,,	64, 80, 80	60	75	550	4,500	100	2·07
Catalonia	,,	51 and 88	60	80	610	3,000	69	2·14
Cephalonia ... ... / Pavonia	,,	52 and 93	66	90	605	4,000	87	2·03
	—	—	—	90	660	—	—	—
Servia	,,	100, 72, 100	78	85	700	9,500	173	1·7
Aurania	,,	91, 68, 91	72	90	764	9,700	180	1·72
Umbria ... ... / Etruria	,,	105, 71, 105	72	110	780	14,500	285	1·83
Campania ... ... / Lucania	Twin-screw, triple, 5 cylinders to each engine.	2 of 37 1 of 79 2 of 98	69	165	805	28,000	—	—
Sylvania ... ... / Carinthia	Twin-screw, triple	22½, 36½, 60	48	180	680	4,200	63	1·4
Skirmisher (tender)	Twin-screw, comp.	21 and 42	32	—	—	—	—	—

TABLE IV.

PARTICULARS OF THE FLEET OF THE P. & O. COMPANY.

	1860.	1870.	1880.	1890.	1897.
No. of vessels owned by the Company ...	39	43	50	51	59
Average tonnage, gross	1,492	1,888	2,735	3,901	4,896
Tonnage of largest vessel	2,283	3,664	4,023	6,600	8,000
Average indicated horse-power	1,148	1,616	2,428	3,759	4,713
Greatest indicated horse-power	2,189	3,300	3,800	7,000	11,000
Greatest boiler pressure, lbs. per sq. in....	21	40	80	160	170
Greatest piston speed, ft. per minute ...	348	468	640	744	894

The first compound engines used by the Company were fitted in the S.S. *Mooltan* in 1861, with a boiler pressure of 27½ lbs.

The first triple-expansion engines used by the Company were fitted in the S.S. *Coromandel* in 1885, with a boiler pressure of 140 lbs.

DISCUSSION.

The CHAIRMAN (Sir Edward Reed, K.C.B., F.R.S., Vice-President): I think you will admit that the idea of the Council in seeking to get one or two papers summarising the progress in the various departments of our profession, made during the existence of the Institution, has been well exemplified in the paper which has just been read by Sir John Durston, a paper which I will point out—more especially to the ladies, who may not be able to follow every part of it quite so readily as I have—will have its value when it comes on record in the Transactions of the Institution. Of course it is a historical paper, and it is one of the greatest value, in my opinion. We do not intend—we hope that we shall not have occasion—to prolong our discussions beyond 2 o'clock, taking this and the next paper; although we can return if necessary, but we should like to hear the observations of a few of our foreign friends and members on this paper which has been read. I understand that Mr. Milton does not wish, as joint author of the paper, to add anything to what has been read. M. Normand, being present, will perhaps oblige us by commencing the discussion.

Monsieur J. A. NORMAND (Member): I wish to express the thanks of the French engineers to Sir John Durston and to Mr. Milton for the very generous manner in which they have acknowledged the part taken by them in the development of the steam-engine. Sir John has alluded once or twice to my boiler. May I be allowed to state that if the name of Normand is to be mentioned, it ought to be more especially in relation to my late brother Benjamin, who has done much more than I have for the progress of the steam-engine. In 1857, he took a patent for the compound engine; in

1860, he built his first engine on this principle, and many more afterwards. It is true that some years later a compound engine was found to have been used previously in Holland, but this historical fact cannot lessen the merit of the engineers who succeeded in proving the importance of the compound engine with intermediate receiver. In 1871 he took a patent for the triple-expansion engine, and in 1873, that is to say, before Mr. Kirk's "Aberdeen," he built several engines on this type. My brother's name is well known in France, but not quite so well in England. I should esteem it a favour if his labours, during the period considered by Sir John Durston, could be mentioned in the records of this Institution.

Mr. A. E. SEATON (Member of Council): Sir Edward, it is, I think, a very fitting thing that you should have presided on the occasion of the reading of this paper, because, from my own personal knowledge, I know how much you have done to further marine engineering in ways that marine engineers have not had sufficient of. The Institution is indebted to Sir John Durston and Mr. Milton for the paper they have given us, because it is very fitting that at times like these we should review the past, and place on record a short history of the progress made in our science. To me history has always been an interesting subject of study, and during the last few years, in the little spare time I have had at my disposal, I have found the study of the history of marine engineering a most engrossing one—so much so that, if there were time, I think I could enlighten the Institution on a good many so-called modern inventions. But I will not detain you to-day by dealing with anything outside the paper, if I can help it. But what is inside the paper is of very great interest, and I know will go down to posterity as a very clear, short, and correct record of what has been done since the foundation of this Institution. I think, sir, the authors—perhaps it was modesty that caused them to omit it—might have alluded to the fact that the progress of marine engineering is in no small measure due to this Institution, inasmuch as the Royal School of Naval Architects and Marine Engineering was initiated and practically founded by this Institution. I think you, sir, were one of the moving spirits in effecting that foundation. To the students at that school much of the advance is due, and that they were able to advance marine engineering was, I am quite sure, due to the very excellent training that they received. It was the first one at which a thoroughly scientific foundation was laid for the superstructure of practical work. I cannot help, in speaking of this, reminding you all that the real progress in the engineering of Her Majesty's Navy was due, initially, to one who has gone—my old friend, Richard Sennett, who preceded Sir John. Up to the time of his taking the reins, the Admiralty Engineering Department was looked upon as a sort of fossilised institution. Outsiders who were trying to impress upon the Admiralty the necessity of making improvements, found it impossible. There were many inventions used in the Mercantile Marine successfully long before the Navy would look at them. But, on the incoming of the late Mr. Sennett, things were altered. He had an open mind on most things, and his thoroughly scientific training enabled him to analyse carefully, and consider well everything brought before him. Unfortunately, death carried him off in the prime of life. His successor is Sir John Durston, and I, as an engineer, am very proud to give him that title, and I congratulate him on acquiring it. I believe he is the first marine engineer who has been so honoured, therefore the greater honour to him for it. He is a very worthy successor, and has done more to promote the engineering progress in Her Majesty's Service than did any of his predecessors. In the paper allusion has been made to the introduction of new designs, due to the application of new material. Now, sir, you have had a considerable share in that. I might remind you that in 1872 you designed what was then called a torpedo-boat catcher, but which in these days is called a torpedo-boat destroyer.

It was for a foreign Government, and you got out, I remember, a very nice design. You instructed me to design the machinery, limiting me to a very light weight, which you did with a great amount of hesitation. You urged me to try and see what I could do with it. We discussed the matter, and I thought, with care in the forms of castings and hollow shafting and rods, we might do it. You were impressed with that idea, and I went to Manchester the next day with a letter of introduction to Whitworth's. I saw the manager there, who declared that by using fluid compressed steel there would be no difficulty in making the hollow shafting. Very much has been said of what is due to the locomotive maker for the advance in ship engineering with the quick-running engines, but I cannot forget that, in the days I speak of, there was a Mr. Thornycroft who had just emerged from Glasgow University, where we heard he had been Rankin's favourite and best pupil. We found in him a kindred spirit, who was anxious to do a great deal with very little metal. In those days Mr. Thornycroft was, as he is now, a very shy and retiring man, and we could not get him to tackle then some of the problems he has solved so successfully since, when he has advanced on his own lines; great credit is due to him, and to Mr. Yarrow also, for the able way in which they have attempted and succeeded in getting huge powers with very small weights. The Mercantile Marine, which at one time was very much in front of the Navy in engineering practice, is now following behind it. There is a paper to be read to-morrow by a very able representative of the Mercantile Marine, and I shall reserve my remarks on that subject till then. In the meantime, I would remind Sir John that Samuel Hall introduced into the *Wilberforce* that which seems to have been forgotten by everybody, namely, distillers for making fresh water to replace that lost by blowing off. In Bourne's book on marine engineering you will see most clearly, in the drawings of the boilers of these ships, the apparatus I have spoken of. At first sight I did not perceive exactly what it was, because my mind was warped into thinking such a modern invention as the evaporator was absolutely new; but, on looking closely into it, I discovered it was, without doubt, the prototype of the modern evaporator, and it had a float and automatic apparatus for feeding as well. We have to-day among us American engineers of note, and I think, for their sake as well as for the sake of truth, I ought to confess here that the application of the water-tube boiler to marine purposes was undoubtedly first made in the United States of America, and that in the very early days of the century. We must also remember that, from that time to the present, various types of water-tube boilers have been invented and patented and tried here and there, but I am quite sure that, in that country, the prejudice against the water-tube boiler does not exist in the same degree that it does in this. Then, again, we must not forget that Jacob Perkins, in the early days of the century, used steam at 700 lbs. pressure, not for propelling engines, but for propelling lots of shots at the rate of five a minute. The application of high-pressure steam by the Perkins boiler was carried out on a large scale by his son, Loftus Perkins, in one or two yachts; but the Perkins boiler was not a success from the same cause as operated in the other ones—want of circulation and means of cleaning prevented their use. Sir John Durston has very properly alluded to the oil fuel question. That is a very important one, I think, as it is held by some high authorities to be the fuel of the future. I, too, think it is the fuel of the future, and is likely to continue so, because its price is such that, while on a small scale it can now compete commercially with coal, directly a considerable demand arises the price will then be raised till it is more costly than coal, and will have to be dropped again. That that is so I can assure you from practical experience. Some twelve years ago creosote refuse, as it was called, was being thrown into the sewers. It was useless for any existing purpose. We found that it had very good heat-giving properties, and tried it on some boilers, and eventually fitted a ship with furnaces adapted to its use; but directly that ship began to run, and there was a steady demand for the

material, it went up from 1¼d. per gallon to 2½d., and even higher. Eventually the tanks were altered into coal bunkers, and the fuel has not been used since. Mr. Holden, the engineer of the Great Eastern Company, has used oil for his locomotives successfully; and, by importing oil refuse from Baku, he is able to continue the service with as good and economic results as with coal. I think by inadvertence the authors of the paper have overlooked the fact that the Messrs. Doxford built a torpedo-boat of considerable size fitted to run with oil fuel. In fact, I believe it was because she was so fitted that she did not find a purchaser. Mr. Doxford, who is here to-day, can tell us, but I always understood that prevented a sale. I have seen Mr. Parsons' boat, the *Turbinia*, running. As a big toy it is interesting and instructive, but much remains to be done, I think, by Mr. Parsons before his motor can be used generally for practical purposes. I think, however, it contains the rudiments of a very useful invention, which, when perfected, as, no doubt, its ingenious and enterprising author can make it, will revolutionise more than one branch of engineering. Allusion has been made in the paper casually to steering engines; we must not forget that without the steam steering engine the high speeds of to-day would not be available, and certainly you could not manœuvre these ships at high speed. The successful navigating, both of Mercantile Marine ships and warships, is due to the steam steering engine, which, to-day, is almost a facsimile of the engine invented by my old and valued friend, Mr. Macfarlane Gray, nearly forty years ago. I say that the modern steering engine—I do not care whose make it is—bears a very strong likeness to the first one I saw fitted in the Navy, which was, I think, in the *Agincourt*; therefore I am justified in maintaining that to his invention is indirectly due the ability of our warships to use the very great power which marine engineers have been able to put into them, and run them at such very high speeds. I must apologise for taking up so much time, but these subjects are of very great interest to me, and I thought I might venture to make some remarks upon them.

The CHAIRMAN (Sir Edward Reed, K.C.B., F.R.S., Vice-President): Mr. Haswell, of the United States, is present, and Mr. McFarland, and other gentlemen from abroad. We are very anxious that they should take part in these debates. I do not know whether Mr. Haswell will favour us with any observations.

Mr. CHARLES H. HASWELL (Member): If I had had time, Mr. Chairman, to consider the very interesting paper which has been read, it would have given me much pleasure to respond to the complimentary call upon me, and, inasmuch as I can fill the void between the period of the commencement of the paper (1859) back to 1828 (which is the year I entered into the profession), I would cheerfully do so; but I am so unexpectedly called upon to address the meeting upon so interesting a subject that I feel that, if I were to undertake to give my recitals, I should not only do injustice to the subject and Institution, but to myself. With your permission, therefore, and that of the Congress, I will avail myself of a fitting opportunity on a subsequent occasion to give you some reminiscences of steam engineering and navigation in its early stages in the United States.

Mr. W. M. MCFARLAND (Visitor): Sir Edward Reed, Ladies and Gentlemen, I feel that I have very little indeed to say; in fact, I can say nothing to supplement this admirable paper, and it is merely because I am the official representative of the United States Navy Department that I endeavour to say anything at all. I had suggested that Mr. Haswell should be called upon, because I presume that he is the oldest engineer present. He certainly is the oldest engineer in the United States, and his life covers practically the whole period of the practical use of steamships, from the time of the *Clermont* on the Hudson River at New York, down to the present day. I felt it would be

a pleasure to everybody here to know this venerable gentleman. The paper itself strikes me as admirable in every way, and there are only a few points on which I have anything to say. Sir John remarked upon the means used at present for the preservation of boilers, and their greatly increased longevity. In connection with that I thought it might be well to call your attention to the fact that the day has passed when we seek for occult causes for very evident things. I remember before the report of the Admiralty Boiler Committee, which investigated this subject of boiler corrosion and put things on a proper basis, everybody accounted for boiler corrosion in some peculiar way. They said that fatty acids were developed from the lubricating oils, and all sorts of things. Yet the method of taking care of boilers then was the very thing that was destroying them. That is all done with now, and I simply remark on it as one evidence of the fact that the time has come when we do not seek for hidden reasons, but look right under our noses for them, where they are usually found. Another point which I think might be mentioned is this. The machinery itself has, in one sense of the term, become simpler than it used to be. I think the general idea is that, because we now have triple-expansion engines, the machinery has become more complicated. There are more parts, but the main engine itself is a more simple affair than it was when I started in the profession. Another fact worth noting is always to bear in mind, in our designing of machinery, that the less complicated it is the more efficient it is sure to be in regular service. It is an absolute certainty that, if complicated things are put on board ship, they are going to be neglected. You cannot send a large enough staff of people to play with toys, and unless the machinery is comparatively simple, so that an honest man, doing his duty, can take care of it, it will be neglected. Now, Sir Edward, besides the venerable engineer who spoke before me, there is another veteran American engineer present, an ex-engineer-in-chief of our Navy, Mr. Shock, and I am sure it would give the Congress pleasure to hear from him.

Mr. W. H. Shock, Chief Engineer, United States Navy (Visitor): I believe there is a saying that the unexpected is constantly occurring. If I had thought that my young friend, McFarland, had intended to call upon me for a speech, I should have given him a peremptory order not to do so. It affords me much pleasure, however, to be here to-day. I have travelled three thousand miles for that express purpose. It is gratifying at all times to be associated with scientific men—men of culture, and advanced thought—men through whose achievements the world is made better. I am especially gratified to be here on this occasion, for the reason that this Congress is held in commemoration of Queen Victoria's Jubilee; a woman who has the respect and esteem of the world. I very well remember, sir, her accession and subsequent crowning. I also remember that, shortly after these events, there were received in the United States engravings of the attractive young lady, one of which I possessed for a number of years. I am here to-day in response to your courteous invitation extended to our Association in New York. My young friend, McFarland, spoke of the "venerable gentleman who had just spoken" (Mr. Charles H. Haswell). I do not know whether he outranks me in age or not, but I am quite ready to concede his right in that particular. While sitting here, I have been looking over my engineering experience of more than fifty years' duration, and the marvellous advancement in naval architecture and marine engineering made during that period. I believe that a careful reader of its history would pause and ask the question, Is this history, or is it fancy? During the first half of the present century, a boiler pressure of 10 to 15 lbs. per square inch was the rule, and a speed of 10 knots was deemed satisfactory. I came across the ocean a few days ago in a ship making 22 knots, with a boiler pressure of 125 lbs. per square inch. One can scarcely realise these remarkable facts, and it is quite impossible to say when economic

considerations of displacement and coal consumption will call a halt in the size and speed of ships. Fifty years ago railroads were in their incipient state. I remember reading that, your distinguished engineer, Stephenson, was asked what difference there would be in the danger of running trains at thirty or fifty miles an hour. His reply was that there would be no difference; if the train left the line at thirty miles per hour, everybody would be killed, and nothing worse could happen at fifty miles. Now we have trains running at seventy miles per hour with safety! History will record that the Victorian Age was the most remarkable period of the world's history; that more had been accomplished in civilising and Christianising the nations of the earth than during all previous times; that the inventions and discoveries of that age are without a parallel. Fifty years ago we had smooth bore guns, and a *steamship* of war was an experiment. I need not call attention to the war-ships of to-day. Again I say that I am very happy to be here, but I cannot thank my young friend for having called attention to my presence.

Mr. JOHN DONALDSON (Member): Mr. Vice-President, Ladies and Gentlemen, it will be a source of comfort to you to know that I have not come prepared to speak at length on this occasion, but I should like to add my tribute to the chorus of appreciation which the paper just read by Sir John Durston has evoked at this meeting. I do not think that sufficient justice has been done to the French in the matter of large water-tube boilers; because, certainly, the *Hirondelle*, a despatch vessel fitted with the Belleville boilers, was running during the Franco-German war, and her commander, Captain de la Tour du Pin, told me some years later, that she was a very efficient vessel, and that he had found her most valuable, more especially in the matter of getting up steam quickly. With regard to the great advance that has been made in steam engineering during the reign of Her Majesty, I would like to say something, if it may not be considered out of place for me to do so, on behalf of my partner, Mr. Thornycroft, who some five-and-twenty years ago, in the *Miranda*, introduced the combination of high steam pressure and increased number of revolutions, which enabled him to get the power necessary to drive that vessel at the rate of eighteen miles an hour, a speed then considered marvellous, and which foreshadowed and led to the still higher speeds of the present day. Sir Benjamin Baker told me that, when he and Sir Frederick Bramwell went to see the *Miranda*, the speed was considered so wonderful that they doubted the possibility of it, and the first question Sir Benjamin put to Mr. Thornycoft was "Where is the trick?" He soon saw, however, that there was no trick, and that Mr. Thornycroft had really made a great advance in steam engineering. I may say, with regard to oil fuel, to the use of which reference has been made, that we have been making some experiments in this direction in a lifeboat we have just built; but the results have not been quite so satisfactory as we should have liked. Personally, I have a preference for coal, more especially for war purposes.

The CHAIRMAN (Sir Edward Reed, K.C.B., F.R.S., Vice-President): I think we shall do wisely, as the next paper is on a cognate subject, if we close this branch of the discussion, and have the next paper read, and complete anything that may have to be said upon both papers. But I would at this stage ask you to concur with me in conveying to Sir John Durston and Mr. Milton, the authors of the paper—unless they have any remarks to make in reply—(Sir John Durston: "No")—our most grateful thanks for the pains they have taken in producing so excellent a summary of the progress of marine engineering from the foundation of this Institution.

WATER-TUBE BOILERS IN HIGH-SPEED OCEAN STEAMERS.

By Monsieur P. SIGAUDY, Member.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 13, 1897; Sir EDWARD REED, K.C.B., F.R.S., Vice-President, in the Chair.]

WITHIN the last two years, water-tube boilers of the small tube type have been used to such an extent, and with such success, that the time has come to examine whether they can be applied to ocean steamers, and whether the legitimate suspicion in which they were held by shipowners and marine engineers is still justified.

Looking back at the history of steam vessels, we notice—and this has been said before—that, during the last twenty years, real progress has been realised by torpedo-boat constructors. They proved that high speeds, till that time considered as unattainable, were realisable, and they opened up the way for the latest improvements.

Referring to the boilers, with the locomotive type torpedo-boats reached 20 knots, or very little more, and Messrs. Thornycroft, Normand, and Yarrow (to name the most prominent constructors) will tell us the difficulties they experienced when they were called upon to increase the speed.

Too often leakages of tube-plates broke off the trials, and sometimes accidents occurred. From the day the tubulous boilers were adopted these accidents have almost entirely disappeared, and the speed has kept on increasing till it has reached, and even surpassed, the incredible 30 knots, and that, too, without any trouble with the boilers.

The same thing is certainly going on in large steamers. They attain 20 knots with great difficulties of construction, such as large size, &c.; but if we want to go ahead seriously we must accept the tubulous boilers.

Certainly a great step has been made with water-tube boilers having large-size tubes, and remarkable results have been attained already; but these boilers would never bear the tests which torpedo-boats undergo. The tubulous boilers of these latter have supported a combustion of 80 lbs. per square foot of fire grate.

Of course, the idea is, not to put a great number of torpedo-boilers on board of a large steamer, no more than Mr. Thornycroft put on board of his first high-speed craft a locomotive boiler without any modifications, but rather to adopt boilers constructed

on the same principle as these, and adapted to the requirements of a long service and great endurance at sea on board a large vessel.

Thus the diameters of the boiler chests must be larger, the tubes that now have about 1 in. internal diameter in the torpedo-boat boiler will be increased to 1½ in., and perhaps a little more. The thickness also may be much greater. Finally, the whole must be so combined as to make the most of the available space and weight of a large vessel.

Accordingly I thought it might be of interest to lay before our Institution a scheme for the installation of tubulous boilers on a high-speed ocean steamer.

The scheme is intended for 23,000 H.P. in actual work; that is to say, from 26,000 H.P. to 28,000 H.P. on trials, and includes sixteen double-ended boilers of the "Normand et Sigaudy" type, divided into two groups of the same size and having two stokeholds for each group. Plate VIII. is the longitudinal section of one group. Plate IX. is the plan; one side shows the stoking floor, the other side the platform for the fans. Plate X. is the transverse section.

The coal bunkers are situated on each side of the vessel, and the two groups of boilers can be separated by a compartment full of coal if convenient.

The dimensions and other particulars of the boilers are as follow:—

Pressure		220 lbs. per sq. in.
Number of boilers		16
Number of furnaces to each		2, divided by a fire bridge.
Number of groups		2
Grate surface for each boiler		95 sq. ft.
Total grate surface		1,520 sq. ft.
Rough heating surface for each boiler		4,650 sq. ft.
Total heating surface, about		74,400 sq. ft.
Tubes	Mean length	7 ft. 8 in.
	External diameter	$1\frac{7}{16}$ in.
	Internal diameter	$1\frac{3}{16}$ in.
	Number for each boiler	1,700
	Number total	27,200
Water	Volume for one boiler	326 cub. ft.
	Total volume	5,216 cub. ft.
Steam	Volume for one boiler	172 cub. ft.
	Total volume	2,750 cub. ft.
Number of funnels		2
Rough section of each		123 sq. ft.
Thickness of material	Upper chest	¾ in. and $1\frac{1}{16}$ in.
	Lower chests	$\frac{11}{16}$ in. and ½ in.
	Smoke boxes and funnels	$\frac{3}{16}$ in.
	Ash boxes, galvanised	$\frac{3}{16}$ in
	Boiler casing galvanised	⅛ in.
	Water tubes	¼ in.

The weights of different parts are as follow :—

	For One Group of Eight Boilers.	For Sixteen Boilers.
	Tons.	Tons.
Boilers complete with mountings	295	590
Water in boilers	73	146
Funnels	50	100
Stokehold plates, floors, &c.	23	46
Feed pumps	7	14
Fans and fan engines	8	16
Feed regulators	1·5	3
Spare gear (50 tons) on board	10	20
Tools and fittings	1·5	3
Total	469	938

If the consumption of coal per I.H.P. of the engines is 1½ lb., which is generally obtained with tricompound engines, the total combustion will be 23,000 H.P. × 1·50 lbs. = 34,500 lbs., or $\frac{34,500}{1,520}$ = 22·7 lbs. per square foot of grate surface, which is very small for a boiler of this type, which in destroyers supports a combustion of from three to four times as much.

The total weight of cylindrical boilers of ordinary shape, having 1,520 sq. ft. of grate surface is, roughly, 1,700 tons. The saving of weight is 1,700 — 938 = 762 tons for the boilers only, but a further reduction may be made also in the engines, when we consider that it is possible to reduce the diameter of the cylinders in consequence of the very high pressure of steam which it is proposed to use with the new boilers.

It is certain that, with a cylindrical boiler a pressure of over 165 lbs. is obtained only with great difficulties in construction. Perhaps such a boiler is not even quite safe. With the small chests of tubulous boilers, the pressure can be increased to 300 lbs., as in the *Pelorus*.

This very high pressure gives the advantage of smaller cylinders, lighter moving weights, less distance between the axes of cylinders, and, consequently, less vibration.

I call your attention to this point: the comparison of weights between the two systems of boilers has been made, supposing the same combustion per square foot of

grate to take place in each, but really the saving of weights could be much greater, since the only limitation to the intensity of combustion in these boilers is the durability of bricks and firebars; therefore, for the same grate surface, the tubulous boilers are much more powerful.

M. Normand has shown that, in vessels where the constant weight to be carried, as imposed by the conditions, such as cargo in high-speed ocean steamers, is small in relation to displacement, any saving in weight conduces to a reduction of displacement more than four times greater, the speed and time of steaming remaining the same. Accordingly a saving of 750 tons reduces the displacement by about 3,000 tons.

Since the dimensions of ocean steamers are limited by the depth of water in harbours, a great increase of speed can only be secured by reducing the weights. These considerations are sufficient to show the great advantages of tubulous boilers, without speaking of the security which results from their employment.

It has been objected that the scale could not be removed in curved tubes. It may be so with some boilers, but with the Normand type we have found that no difficulty whatever was experienced with a suitable chain and scraper. Even with straight tubes a chain is necessary, on account of the small diameter of the chests.

At the meeting in June, 1895, I had the honour to lay before you a paper on the coupling together of two boilers of different systems on the tug *Adour* of Bayonne, one being a return tube boiler, and the other a tubulous boiler of the Normand type. Since this date the coupling together has given no difficulty, and, confirming my prognostications, the tubulous boiler has given better results than the return tube. From the engineer's log-book it appears that the water-tube boiler has been employed more frequently than the other, on account of its ability to raise steam more quickly. It has never been stopped for repair, only a few fire-bridge bricks having had to be replaced. The consumption of coal has been, roughly, 10 per cent. less in the Normand boiler than in the other.

The history of ocean steam navigation may be divided into several periods, each of which marks an advance on the preceding one. Up to this day, the greatest improvements have been :—

(1) The substitution of the screw for paddle wheels.

(2) The adoption of compound engines.

(3) The triple and quadruple compounding.

The next step will be the adoption of the water-tube boiler, and it will prove to be an advance of still greater importance than any of the former ones.

DISCUSSION.

Mr. JOHN SCOTT, C.B., F.R.S.E. (Member of Council): Mr. Chairman, it gives me great pleasure to respond to the call that has been made upon me, rather unexpectedly, to speak upon my friend M. Sigaudy's paper. But I will just say a word on the subject, from the very great respect which I bear to him. He has brought a subject before us on this occasion, more in reference to the application of small tube boilers in the merchant service high-speed ocean steamers than that with which we are more familiar—the question of warships. Certainly, up to this point, with the exception of the great French steamship company, tubulous boilers in merchant ships have not had much vogue. If we are to take the figures which M. Sigaudy places before us, with the large knowledge which he has upon the subject of the Normand and other types, I think there is a case made out for the adoption of this type; but, there is always the fear before the eyes of those who might be disposed to try this type of boiler for mercantile purposes, that they would not be sufficiently lasting to make it a commercial success. Until that is proved, I fear that the adoption of this or any other type of tubulous boiler will not make real progress in the merchant service. I myself constructed a vessel, which was named in Sir John Durston's paper, in 1857. I spent a great deal of money over the construction and work of that vessel; but the boiler, which was not unlike those of the Normand type, failed, not from the reasons pointed out in Sir John Durston's paper, but from internal corrosion.

The CHAIRMAN (Sir Edward Reed, K.C.B., F.R.S., Vice-President): Other engagements had taken Sir William White into the great hall during the debate on Sir John Durston's paper, otherwise I should certainly have asked him to favour us with his views. I think we are all interested in what Sir William White may say, particularly after the splendid manifestation of his highly capable work at Spithead, last week. If Sir William White will speak on this second paper—and, I may say, also on the first paper, because we were rather premature in closing the discussion—I am sure we shall all be delighted to hear him.

Sir WILLIAM WHITE, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): Sir Edward Reed, Ladies and Gentlemen, I have had the opportunity of reading this paper before it was printed, and it seemed to me one of great suggestiveness and great value to lay before the Congress. It raises the important point whether we have reached a stage in the use of small diameter tubes in the water-tube boilers that will justify their application on a very large scale to sea-going ships. M. Sigaudy has spoken more particularly of the ships of the Mercantile Marine; but, no doubt, his remarks would apply equally well to high-speed ships of war. There are, of course, many obvious and well-proved advantages in this type of water-tube boiler. But before an experiment was made on such a large scale as is proposed in this paper, those gentlemen who would have to take the responsibility would necessarily require to look very carefully into the question from all sides. There are many things which are justifiable up to a certain scale which it would be unwise to apply on a much larger scale. We all know that developments of power are possible with a certain limited number of boilers of any type, which cannot be reproduced *pro ratâ* with a much larger number of boilers of the same type. As one who would be only too glad to see the small diameter tube boiler come into use, if it could justify itself, because it promises so many advantages, I should like to put some questions to those who advocate that type, and to know their real feeling and knowledge on such points as these:—First. Will this great saving of weight in relation to power, which is claimed in the paper, be realised in long distance steaming at sea? It may be so; or it may happen, when the problem to be solved is

that of steaming continuously over long distances with endurance and economy, that the saving in weight would not be anything like so great as is suggested in the paper, especially when applied to very large powers and high sea-speeds. Then there are the questions of examination, maintenance, and durability. In all these we can only depend on experience to settle the point. I hesitate to express any opinion on the matter in the presence of the Engineer-in-Chief; but I may say that the Admiralty has attacked these problems from the smaller end, and we shall know more about it by and by. But it is an important matter to know what may be expected from this type of boiler for long distance steaming, with continued economy and boilers kept in good condition. I do not know of any experience bearing on that point. I have endeavoured to ascertain facts from those who are most experienced in this type of boiler, and I have not been able to elicit such information of a definite character as would enable one to form an opinion. Perhaps some of these gentlemen now present will say whether I have misjudged. It does not seem to me—it is a minor point—that M. Sigaudy is quite fair in taking the grate surface as the unit of comparison. I think if he would add heating surface, and let us know how much he intends to take out of the boiler in heating surface in ordinary working, it would be an interesting addition.

Sir JOHN DURSTON, K.C.B.: He does so—80 lbs. per square foot, on the first page.

Sir WILLIAM WHITE: I am very sorry I should have missed that point in glancing hastily through the paper again this morning. That, of course, is a more ample surface than would be allowed on the cylindrical boiler on Atlantic service. The points I particularly wished to have discussed, and to get information upon, are those that I have now specially mentioned. But, before I sit down I may add that, in some of the new cruisers now building in France, I believe there is contemplated an installation of boilers not very dissimilar from that described in the paper, and that exhaustive experiments are in progress with such boilers. If that is so, matters have been carried in France a step beyond what has been so far done here. The largest experiment we have made with small tube boilers gives a maximum development of about one-fourth of the maximum power which is here proposed, 7,000 H.P. as against 28,000. I am sure we shall all watch with the greatest interest the development of this type of boiler. We owe so much to French ability and French boldness in this matter of water-tube boilers already, that we shall be only too glad to increase our acknowledgments when this great experiment takes place, and we are able to get the benefit of the information obtained.

Mr. J. I. THORNYCROFT, F.R.S. (Vice-President): Sir Edward Reed, Ladies and Gentlemen, the paper before us by M. Sigaudy is perhaps a little bold, but I feel there is truth in what M. Sigaudy says at the end of his paper. He promises that the next step will be to use the small tube boiler for large powers. But there is also very much truth in what Sir William White has told us. He says we have not at present that experience which will justify us in working these boilers at a high rate.

Sir WILLIAM WHITE: And for long periods.

Mr. THORNYCROFT: That is, of course, the essence of the problem. If these boilers are to be used, as I imagine they will be some day, in our large ships for long voyages, I think we shall have to face difficulties to which at present we are not able to give quite a satisfactory answer. When these boilers are used for very high powers for a short time the difficulty of the fire-bars is one which is unimportant, but if they continue to be worked at this very high rate, burning as much as 100 lbs.—M. Sigaudy said 80 lbs.—to the square foot, that is quite impossible for a lengthened voyage. At

present we have not got the information which will tell us definitely what the fire-bars will stand. I understand from Sir William White that the figures M. Sigaudy gives do not tax the grate surface.

Sir WILLIAM WHITE: Twenty-two, he gave.

Mr. THORNYCROFT: I understand that has been exceeded in the flue boiler. What I would remark is that there is nothing in the nature of a problem which will enable the furnace in the flue boiler to burn more coal than could be done by proper arrangement in the tube boiler. But I may say that these boilers have been developed for a particular purpose, and they are, almost without alteration, put into large vessels. Now that is not quite fair. The constructors should be asked to attack the problem which Sir William White sets before us, and I take it, for that purpose, we must reduce the ratio of the heating surface to the fire-grate, and build a boiler where we tax the heating surface to all it can stand, also using our fire-bars for all we can get out of them for a lengthened period. I think, in that way, we could make lighter boilers, and durable boilers, that would answer our purpose. My firm would be happy to spend time on that subject. With regard to the development of the water-tube boiler, I think what Sir John Durston has told us is rather interesting—that we had a square boiler at first; it became an oval boiler, and afterwards a round boiler. That boiler became a small boiler, and we now come to the tube boiler. The question is, how small you can make those tubes. What is being done now has been justified by experiments which have been made, and we have got, for large ships, tubes down to 4 in. or 5 in. in diameter, with a consumption on the fire-grate of about 45 lbs. of coal to the square foot. I think we can still further reduce that diameter. Perhaps it will be found that something intermediate is more suitable; that is, the construction of boilers for the greatest powers in which the saving of weight can be utilised to the utmost, so that any saving in the boiler can be saved again in the ship and the engine. At this late time I wish merely to say that I think this meeting is justified by the attendance we have, and I am very glad that the efforts of the Institution have been so successful in bringing together our foreign friends for the advancement of the science we study.

Mr. LESLIE S. ROBINSON (Member): Sir Edward Reed, Ladies and Gentlemen, at this late time I will not add more than one word. The question raised by Sir William White is a very pertinent one indeed, and one of the best ways in which I can answer it is to draw your attention to the following fact. Water-tube boilers of the large tube type were adopted by the French Government some considerable time ago, and our own Admiralty, after carefully examining the question for themselves, have now come to the conclusion that they are justified in adopting this type of boiler for our largest boats. The French Admiralty have now gone one step further, and adopted small tube boilers in several of their largest boats. We shall watch with the greatest of interest the results of this experiment, on no mean scale, and those results will be the best answer as to whether these boilers will, or will not, stand long continuous steam. In closing, allow me to thank you on behalf of M. Sigaudy for the very kind and appreciative manner in which you have received this paper, and to express his great regret at his inability to be present to-day.

The CHAIRMAN (Sir Edward Reed, K.C.B., F.R.S., Vice-President): I move that our best thanks be conveyed to Mr. Sigaudy and to Mr. Leslie Robinson for having presented this valuable paper, and raised such an important debate. I confess I should like to have heard some words from Mr. Yarrow on the subject, because I know he has very pronounced views. I have been unable to get a promise from him to speak. However, perhaps other opportunities will arise. I hope you will all join with me in a vote of thanks to M. Sigaudy for his very interesting paper.

The following reply to the discussion has been communicated by M. Sigaudy, who was not present at the reading of his paper :—

Mr. JOHN SCOTT fears that small tube boilers might not be sufficiently lasting for commercial purposes, and lead to internal pitting. This pitting is as likely to occur on large tube boilers as it is on small tube boilers, or even on the ordinary Scotch boiler when working at high pressures, if care be not taken to feed the boilers with fresh water purified from all grease, &c. I may perhaps cite the case of the torpedo-boats used for continuous pilot service, which most nearly resemble the conditions obtaining on commercial vessels, and the tubes of these boilers, which are 1 in. internal diameter, have not suffered from internal pitting. I might further remark that the loss of a few tubes in a tubulous boiler is a matter of no more importance than it is in a condenser, on account of the large number of tubes. All that is necessary is to plug them, which can be done in a comparatively short time, and to continue to use the boiler until such time as the number of tubes that have been plugged affects the power of the boiler. On torpedo-boats the fact remains that from the point of view of the life of the tubes and repairs, the small tube boilers are admittedly better than those of the locomotive type, and there is no reason why this same advantage should not hold for boilers of larger ships. The difference between the boilers of these latter and those of the torpedo-boat class are similar to the difference existing between the Scotch boiler and the boiler of the locomotive type. Sir William White asks whether the small tube boilers have sufficient endurance for a long and continuous service. In reply I may say that, given an equal life for the grate and other furnace mountings, whatever be the type of boiler, and the same rate of combustion, the question resolves itself into one of the life of the tubes exposed to the fire. If boilers are fed with fresh water, it is very difficult to give a limit to the life of these tubes ; but, if the feed-water contains salts and other corrosive substances that attack the metal, all high-pressure boilers will deteriorate. The question may be stated thus : Is it preferable to have the leaky tube-plates which occur on the type of boilers at present in use, or merely to condemn one or two tubes in a boiler in which there are a very large number of tubes ? I must leave this point to the experience of the owners and builders of steamships. It cannot be denied that if a tube gives out while under steam it necessitates putting the boiler out of action for the time necessary to plug a tube, that is to say, for a few hours ; but the vessel itself is not thereby stopped or impeded, because the elasticity of these boilers enables the engineers to drive the remaining boilers somewhat harder without any serious disadvantages. For instance, on the Transatlantic liner, fitted with the boilers as I have described them, 24·2 lbs. would have to be burnt per square foot of grate instead of 22·7 lbs. In regard to the ratio of heating surface to grate surface, I adopted the figure 48, which is much higher than that in vogue on "Scotch boilers," and it is a very ample allowance for boilers where the hot gases circulate all over the external surface of the heating tubes ; whereas, in the case of the flames on the inside of the tubes, those gases that pass down the centre of the tube are not brought in contact with the heating surface at all. Mr. Thornycroft finds my proposal a "little bold," but I think you will all agree with me that the conception of his early small boats, at a very high speed, was at the time they were brought out much more audacious than my proposal, and yet actual experience has more than justified his early dream.

PROCEEDINGS ON TUESDAY, JULY 6.

A GENERAL Meeting of the Institution of Naval Architects was held in the Great Hall of the Imperial Institute on Tuesday, July 6, at 3 p.m., for the purpose of electing new Members and Associates. The Right Hon. the Earl of Hopetoun, G.C.M.G., President of the Institution, occupied the chair.

The following gentlemen (having been duly recommended by the Council) were unanimously elected Members of this Institution:—Mr. Edward Lewis Attwood, of the Controller's Department, Admiralty, Whitehall, S.W.; Mr. Dacres C. Beadon, Outside Manager to Messrs. R. & W. Hawthorn Leslie & Co., Newcastle-on-Tyne; Mr. Kenneth Barclay Brown, Managing Director to Messrs. Brown's Dry Dock and Engineering Company, Limited, London; Mr. Robert Craig, Marine Superintendent to Messrs. John Wood & Co., of London and West Hartlepool; Mr. Lewis George Davies, Civil Assistant, H.M. Dockyard, Portsmouth; Mr. William Thomas Davis, Assistant Constructor in H.M. Dockyard, Portsmouth; Mr. William Graham, Manager to the Tyne Engine and Ship Repairing Works, Barry Docks; Mr. Joseph Hallett, Principal Assistant to Archibald Thomson, Consulting Marine Engineer, Fenchurch Street, E.C.; Mr. William Isaacs, Superintendent to Messrs. R. Singlehurst & Co., Liverpool; Mr. John William Jack, General Manager in the Shipbuilding Yard to Messrs. Day, Summers & Co., Southampton; M. Juste Theodore Jean de Bruyn Kops, Naval Architect and Consulting Engineer, Holland; Mr. William Laurie, Marine Superintendent to the Palace Steamers, Limited, King William Street, E.C.; Mr. Andrew Maclean, jun., Managing Director of the Shipyard of Messrs. Barclay, Curle & Co., Limited, Glasgow; Mr. Frank Theodore Marshall, General Manager to Messrs. R. & H. Hawthorn Leslie & Co., Newcastle-on-Tyne; Mr. Frederick Maurice, of the Chilian Naval Commission in Europe, Agate-road, Hammersmith; Mr. William Allan Oglethorpe, Assistant Superintendent, Mersey Docks and Harbour Board, Liverpool; Mr. James Richard Piper, Master Shipwright, Milton, near Gravesend; Mr. James Venn Paterson, Naval Architect to the International Navigation Company, Philadelphia, U.S.A.; Mr. James Robinson, Works Manager at Messrs. Sir Thomas Richardson & Sons, Limited, Hartlepool; Herr Wilhelm Renner, Director der Schiffswerfte der Donau Dampfschifffahrts-Gesellschaft, Budapest, Hungary; Mr. John George Royal, Manager of the firm of Messrs. The Executors of F. A. Walker, Sudbrook; Mr. Charles E. Sinclair, Assistant to Mr. James Maxton, Consulting Engineer and Naval Architect, Belfast; Mr. Taisuke Shiota, Chief Draughtsman to the Mitsu Bishi Dockyard and Engine Works, Nagasaki, Japan; Mr. Hugo H. Sillichöök, Chief Constructor in the Swedish Navy, Stockholm; Mr. James A. Spence, Superintendent Engineer to Messrs. Watts, Watts & Co., London; Mr. Victor Garland Shilston, late of the Nile Engine Works, Cairo, Egypt; Mr. Charles Humphrey Wingfield, of the Engineering Department of Messrs. John I. Thornycroft & Co., Chiswick.

The following gentlemen were elected Associates:—Mr. W. C. Angove; Mr. H. Benham; Mr. James Caird, Mr. J. Carlisle, Mr. J. L. Carozzi, Mr. G. W. Colman, Lieutenant J. C. Colwell, U.S. Naval Attaché; Mr. H. Cooper, Mr. A. Colville, Captain Percy Cullen, Major A. H. Davis, Herr Paul Dvorkovsky, Herr T. H. Heidmann, Mr. J. M. James, Herr W. Kestvanek, Mr. A. Lindley, Mr. R. P. Lyle, Mr. A. Wylie, Mr. T. Perkins, Captain F. J. Pitt, R.N.; Mr. E. O. Sachs, Mr. D. Sinclair, Mr. R. B. Stoker, Mr. T. Utley, Mr. A. Vickers, Mr. C. D. Willard, Mr. W. Wills, Mr. A. Wilson, Mr. W. G. Wilson, Dr. H. Wiegand.

ON THE ADVANCES MADE IN THE MATHEMATICAL THEORY OF NAVAL ARCHITECTURE DURING THE EXISTENCE OF THE INSTITUTION.

By Sir EDWARD J. REED, K.C.B., F.R.S., Vice-President.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; the Right Hon. the Earl of HOPETOUN, G.C.M.G., President, in the Chair.]

AT the first meeting of this Institution, on March 1, 1860, the late Dr. Woolley, who was in the highest degree qualified for the task, read a paper on "The Present State of the Mathematical Theory of Naval Architecture," in which paper the whole ground covered by the title was well surveyed. It was possible at that time for a man like him to go hastily over the field of scientific naval architecture, for its advancement, in all the generations that had gone before, had not carried it beyond the grasp of an individual, or the compass of a single discourse. The Council of the Institution, in this year of great commemorations and congresses, has thought it well to impose upon me the task of presenting a brief notice of the progress made in this field during the existence of the Institution, and, as the subject is so extensive, I will spend no time on apologies for undertaking the duty cast upon me. Such a summary of actual progress can have no claim to novelty, or to any other merit than that of a generous notice of the labours of others; but, however imperfect, it cannot fail to illustrate the fact that, if the Institution of Naval Architects has powerfully assisted, as I am sure it has, in advancing the theory of our profession from its state in 1860 to its present condition, then has it taken a very important part indeed in that scientific expansion which is perhaps the greatest glory of our Sovereign's reign.

The mathematical theory of naval architecture naturally separates itself into the following divisions:—(1) The science which deals with the strains to which ships are subjected at sea, and with the provision of the strength necessary to withstand them; (2) the science which regulates dimensions, forms, and weights, so that vessels may float under all conditions with due displacement, draught of water, and stability; and (3) the science which provides for so adapting form to fluid resistances that vessels may be propelled, either by external or by internal forces, with due economy and security.

The first of these divisions occupied no part of Dr. Woolley's paper, but I have introduced it here, because of the great importance it has assumed in these days

of long and large ships. A full exposition of its principles would have to start with an investigation of all the strains to which ships are subjected, and to comprise a theoretical explanation of the manner in which these are all provided for. This investigation has not, within my knowledge, yet been made, or even attempted, in any connected or exhaustive manner. The transition from wood shipbuilding to iron, which had made some progress in 1860, has been succeeded by the abandonment of iron for steel, and nickel steel now appears likely to replace steel; while other alloys, such as bronze and aluminium, have occasionally been more or less employed. It would be a great advantage, doubtless, were a theory of strain and of strength worked out in such a form as to prescribe minimum scantlings and proper butt and joint connections for all forms of sea-going ships, and for all parts of them, adjustable by means of constants to the use of various metals of known strength and durability. But the production of such a theory, and its embodiment in appropriate formulæ, is a task reserved for the future, and is one not unworthy of the labour of some of our younger men. All that has been done in this respect during the existence of our Institution is to prepare the way for such a theory, and much work of this preparatory kind has been accomplished. The Transactions of the Institution abound with records of partial investigations, calculations, and experimental data.

In dealing with this particular matter I find it necessary to summarise in three or four sentences the early work done upon it. A century and a half ago, the famous French originator of so much of our naval science, Bouguer, in his "Traité du Navire," projected estimates of the strains upon ships, of no great value in themselves, as his assumptions were very wide of the truth, as he acknowledged; but he nevertheless laid down the system of graphically representing relative displacements and weights, from point to point, along the length of the floating vessel, which is in principle what we still do for a like purpose. A few years later Euler, who was Director of the Prussian Academy of Science, produced his famous treatise on rolling and pitching, in which, although he dealt but little with statical strains, he nevertheless took note for the first time of the longitudinal bending effect produced in a ship by the longitudinal pressure on the immersed part. In a later work ("Théorie Complète"), this author again dealt with the subject; but, like his predecessors, attempted no quantitative estimates of strain. Romme followed Bouguer's line of inquiry, and then Seppings, in this country, took the matter up, but advanced it little himself, his practical work upon ships, however, being referred to our Dr. Young—a man remarkable at the beginning of this century for mastery in several branches of science. The Doctor examined and reported on the subject to the Royal Society, giving quantitative results from actual ships, and taking into much fuller view than any previous writer the principal causes of straining in ships. The celebrated Dupin reviewed the work of Seppings and Young, and cast much light upon the subject.

It remained pretty much as he left it (so far as I know) until I entered upon the subject at the Admiralty in 1869, at a time when it had become of great importance, and when I enjoyed the signal advantage of having upon my staff, and available for this purpose, a naval architect who has since become well known to fame, and has distinguished himself greatly as the designer of many of the finest warships in the world —Sir William White—and with him our lamented friend Mr. W. John. The line of investigation adopted by us, which was of the most practical character that could be given to it—our calculations being founded upon the graphical representation of the buoyancy and weights, estimated in short lengths from stem to stern, of several of H.M. ships of different types—developed results very different indeed from some of those which had hitherto been accepted, and disclosed consequences which had not at all been foreseen.* In the year 1874 Mr. Wm. John read a paper to this Institution in which he summarised this system of inquiry, which I had previously applied only to certain of H.M. ships, and extended it to vessels of the Mercantile Marine. This paper was followed by another, in 1877, from the pen of the same able investigator, who, I may say, after receiving the highest available training in H.M. School of Naval Architecture, and at the Admiralty, had become one of the leading members of the staff of Lloyd's Register Office under our eminent and valued friend Mr. Martell. In his first paper Mr. John displayed, in a remarkable manner, the tendency that then existed—when, as now, larger and still larger ships were continually coming into vogue—to bring the materials composing them under continually greater tensile strains per square inch as the ships increased in size, as illustrated in the following table, deduced from calculations made on a series of vessels that were at the time fairly representative of the Mercantile Marine of this country:—

Tonnage of Vessel.	Maximum Tension on the Upper Works in tons per square inch.
100	1 67
200	2 36
300	3·09
400	3 55
500	3·95
600	3·72
700	4·57
800	4·59
900	4·8
1,000	5·19
1,500	5·34
2,000	5 9
2,500	7·08
3,000	8·09

* These investigations were published *in extenso* in the Transactions of the Royal Society in 1871, and were pretty fully reproduced in "Naval Science," Vols. I. and II. The summary of them given at the commencement of Mr. John's paper of 1874, about to be mentioned, though brief and imperfect, absolves me from the necessity of repeating here any part of these investigations or of their results.

All these vessels approximated to the proportions of eight breadths in length and eleven depths in length, their scantlings representing, as fairly as possible, those generally adopted at the time for first-class vessels. After also estimating the strength of some vessels above 3,000 tons, the author was induced to believe that their maximum tension ranged in many cases between 8 and 9 tons per square inch. "In a vessel over 400 ft. long, whose strength I investigated quite recently, I found the maximum tension 8·85 tons. These forces," he said, "are not sufficient in themselves to cause rupture in a vessel well built of good materials; but they may be sufficient to cause very considerable straining, which, if not attended to in time, must weaken the vessel to the point of danger." As ships at that time were mostly built of iron, of which the tensile strain did not, as a rule, exceed, or much exceed, 20 tons per square inch, it is obvious that the factor of safety was not more than $2\frac{1}{2}$, and, therefore, much below that assured to structures on land. The late Sir William Fairbairn—no mean authority of his day—in his work on "Iron Shipbuilding," advised that the strain brought upon the material should not exceed one-fourth, or one-fifth, of its ultimate strength, on account of the fact that the changes of strain are not merely effective as regards their *amount*, but also as regards their *direction*. His final conclusion was that, with iron, a strain of 5 tons per square inch on the material, acting alternately in opposite directions, would at least injure, if it did not ultimately fracture, the material after a great number of alterations. Professor Rankine also considered that the strain should not exceed one-fifth of the ultimate strength.

The first paper of Mr. John had nothing of the alarmist character about it, erring, if at all, the other way; for, after discussing in detail a ship the tension upon whose deck stringer plates rose to more than 8 tons in some conditions of lading and some states of the sea, he refused to pronounce her as unsafe, or dangerously weak for the trade she was in, or even to say that "she is a weak ship as ships go," alleging that she had for years been doing her work in an unexceptionable manner, and acknowledging that we did not often hear of vessels breaking in two afloat. He confessed, however, that "we are trespassing on the margin of surplus strength to an extent which creates in my mind an uncomfortable feeling." In his later paper he had to acknowledge that several cases of vessels breaking asunder at sea had come under his notice, and he investigated very fully the case of a comparatively small vessel (210 ft. by 25 ft.) which broke in two from the excessive amount of compressive strain cast upon her upper deck at sea. This was a vessel of light draught, and the sagging strains when she was stretched across the hollow of a wave of her own length were by far the greatest strains to which she was exposed. It was a case analogous to, but much worse than, that of the *Victoria and Albert* given in my own Royal Society paper. I will only add in this connection that Mr. John very properly drew attention to the great difference that undoubtedly exists between the case of land structures exposed daily to the fatigue of

enduring the maximum weights and strains, and the case of a seagoing ship which has only to endure them occasionally. The point is so vital to a just appreciation of the matter as he left it—and I do not think this aspect of it has been much advanced since—that I add the following paragraph from his second paper:—

"In engineering structures of iron, 5 tons per square inch would be considered quite as high, and in many cases higher, than it would be prudent to go with the working load; but this would be for an everyday load, and there is a marked difference between such cases and the exceptional strains of a ship. For ordinary working loads and fair weather strains, perhaps no engineering structures in existence have larger margins of surplus strength than iron ships, and this helps them the better to bear exceptional strains. There are, of course, limits which should govern the margin of safety against exceptional strains, but it is a difficult matter to deal with them, and they can only be arrived at by very careful attention to the teachings of experience and an accurate investigation of the facts bearing on the subject as they arise."

It would be leaving the general question of our recent progress in respect of strain and strength in a very imperfect condition, if I failed to take passing note of three remarkable papers submitted to the Institution in the years 1882, 1890, and 1894 respectively by three naval architects, two of whom have unhappily been taken from us. I refer to the papers "On the Transverse Strains of Iron Merchant Vessels" (1882), by the late Professor Jenkins and the late Mr. T. C. Read; another (1890) having special regard to "The Distribution of Shearing Stress over the Transverse Section of a Ship," by the former; and a third (1894) by the late Mr. Read and another accomplished member of Mr. Martell's staff at Lloyd's Register Office, Mr. Stanbury, exhibiting certain detailed verifications and limitations of well-known formulæ of stress and strain, and I gladly avail myself of this, the first, opportunity which my paper affords of expressing in general terms the deep obligation which this Institution owes, in my opinion, both to Mr. Martell and to his predecessors at Lloyd's Register Office, for the help afforded us, from our very first session until now, in every department of our work.

The first of these papers presented the first close mathematical investigation of the distribution of transverse strains with which I am acquainted, but it was confined to the case of a vessel in dock, without cargo, kept upright by breast shores only, and supported by the keel alone. The results demonstrated the need of great transverse strength in the engine and boiler spaces of a steamship, "where the localised weights of the engines and boilers, and the want of support from the deck above, due to the small number of beams, increase the strains at the middle line and the bilge." To the second paper I will presently devote a paragraph. The third paper, by Messrs. Read and Stanbury, is an extremely valuable one, as it exhibits in much detail the degree of correspondence which they found to exist between the well-known stress formulæ—

$$\frac{p}{y} = \frac{M}{I} = \frac{E}{\rho}$$

and—

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$

first in the case of certain rolled Z-frames and channel bars, and of certain riveted steel and iron frames with riveted reverse frames; and afterwards in the case of actual ships. The general result reached was that "there appears to be good reason for supposing that the actual deflections of a vessel do not differ greatly from those which are obtained by calculation." This result should be borne in mind, notwithstanding the admissions which I am bound to make in the next paragraph.

I must now devote a few words, as promised, to the paper of Professor Jenkins of 1890. This paper was of much value in helping us to assign quantitative values to the "shearing stresses" exerted at sea upon various parts of a ship's section, and thus indicating both the causes of, and the remedies for, much of the weakness which has been observed to exist in parts of vessels, chiefly at and above the turn of the bilge. The investigation was, in this respect, founded upon the fact (long before referred to by Rankine in his work on shipbuilding) that the shearing stress is not uniform over a section such as that of a ship. No exception can be taken to the work of Professor Jenkins in this particular. But the Professor's paper points to the necessity of making perfectly clear what he seemed not altogether to apprehend†, viz., that all the investigations concerning bending moments and inferred strains initiated by myself, with the aid of Sir William White and Mr. John, were perfectly well known by us (and we thought by everyone) to be but approximations to actual moments and strains, and subject to modifications whenever, in the progress of science, it might become possible (*a*) to select for each ship the wave or waves best adapted to her form from point to

---

* p = the stress at any particular point;
y = the distance of the point from the neutral axis;
M = the bending moment of the impressed forces;
I = the moment of inertia of the section of the beam through the point, and perpendicular to the neutral axis, about a line through the neutral axis, at right angles to the forces bending the beam;
E = the modulus of elasticity of the material of which the beam is composed; and
ρ = the radius of curvature of the neutral axis of the beam under the loads.

† In Professor Captain Kriloff's admirable paper of last year, on "A new Theory of the Pitching Motion of Ships on Waves," referring to my investigations, it was asked, "Is the approximation so obtained sufficient?" in other words, "Is it possible to neglect the *inertia* of the ship's pitching motions?" If the gallant Professor had consulted my Royal Society paper he would have found this matter discussed on pp. 445 and onward. It was distinctly pointed out that increased strains would result from the vertical movements of the ship and the sea respectively. He is perfectly correct in his own views upon the matter; but he failed to observe that they had been anticipated.

point, as well as to her length; (*b*) to so analyse the structure of waves as to determine precisely how much upward pressure they exert upon a ship in transit across them at each step of the transit; (*c*) to determine by these and other means the precise variations in the effective forces of gravity, if I may so speak, of both ship and water at the crests and hollows of the waves selected; and, generally, to introduce all those refinements, and those quantitative corrections, to which our somewhat rough process of assuming for our ship momentary statical equilibrium upon wave crests, and in wave hollows, was of course liable. I do not hesitate to say that all these obvious qualifications of our results were perfectly present to the minds of Sir William White, Mr. John, and myself, when we worked upon the subject at the Admiralty, and when, almost as soon as they were obtained, our results were communicated in the form of lectures to the students of the Royal School of Naval Architecture, so many of whom have done honour to their training. It is most necessary to have the approximate nature of such calculations clearly understood. Subject to that, the question of shearing stresses was not only treated in my Royal Society paper and lectures more than twenty years before, but it was even then also carried by Messrs. White and John much beyond the bounds of such publication as they were then able to give to them. I believe, nevertheless, that Professor Jenkins was the first to bring into scientific and quantitative form, for the service of naval designers, the question of the due distribution of strength throughout the section to meet the real distribution of the shearing stresses.

I have made this first division of my paper of some length, because I believe the whole subject, as understood and worked out in practice in so far as this country is concerned at least, to be the product of the period covered by the title of my paper—the fruit, in fact, of that tree which was so fortunately planted when this Institution was founded. It has nevertheless to be repeated that we are very far from possessing a comprehensive theory of strains and strengths, such as might enable the designer at once to apportion the latter to the former in all cases. This is acknowledged by the very highest authorities. At a conference of Naval Architects held a few weeks ago in London, I drew attention to the remarkable nearness that exists between the strengths of ships and the estimated strains at sea to which they are subjected, pointing out that shipbuilding practice presents us with no such large "factors of safety" as we all require in bridges and other land constructions. Sir William White and other speakers truly pointed out that practical experience has made it certain that no such large factors of safety are really requisite in ships. But it seems equally certain that no one can say at present what the factor should be, even as regards longitudinal strength, and its determination is one of the results to which we may confidently look forward.

In coming next to the regulation of dimensions, forms, and weights of vessels in order that they may float with the necessary draught, displacement, and stability, we enter upon a division of the subject which itself naturally separates into two sub-

divisions: viz., calculations of immersion with the vessel at rest, or presumed to be so; and calculations of movements under the influence of disturbing forces, other than those of propulsion.

The calculation of the volume of a ship's immersion has undergone some development since the Institution commenced its labours. The field, however, is a somewhat limited one, and no revolutionary or large changes have been, or can be, effected. In our first paper (1860), Dr. Woolley presented us with a novel and elegant method of his own for estimating the cubical contents of a solid body bounded on one side by a surface of varying curvature. I doubt if that method has ever been sufficiently appreciated, and put into operation, outside of the Admiralty, although it greatly facilitates the calculation of both the displacement and centre of gravity, and might be used with like advantage for calculating the internal capacity of a ship. In 1865, a lamented former secretary of the Institution, who was also Principal of the Royal School of Naval Architecture more than once, the late C. W. Merrifield, presented us with a series of papers or notes upon this section of the Geometry of our subject, bearing testimony to the value of Dr. Woolley's contribution to it as being "one of the most interesting and useful additions to our rules of calculation which have been given during the present century." He claimed for it a degree of accuracy considerably in advance of any measurements which the shipbuilder can obtain from either his drawings or his frames; and, acting in concert with the Doctor, extended the principle to a triple integral. Just as Simpson's first rule applies to the cubic parabola, and Dr. Woolley's to the cubic paraboloid, Merrifield's rule applies to the ternary cubic. The late Mr. H. J. Purkiss (whom we lost by a deplorable accident in the very flowering of his great mathematical talent), taking note of the work of Woolley and Merrifield, sought out a general formula for a multiple integral, of which the Simpson, Woolley, and Merrifield rules would be but particular cases, and obtained an expression which proved equivalent to Simpson's first rule when the variable was but 1, to Woolley's rule when the number of variables was 2, and to Merrifield's when the number was 3. It clearly exhibited the connection between those three cases, and showed that their resemblance was not accidental. The other papers of Merrifield were "On successive Integration, arranged so as to yield Ordinates for a Scale of Areas"; and on "The Measurement of curved Surfaces by means of Ordinates." These papers gave brilliant expression to the ability with which Mr. Merrifield brought his great mathematical powers to bear upon problems which are of profound interest to our profession, and not without value in other professions. Mechanical aids to the calculation of areas have so much reduced the actual work and time required as to diminish greatly the relative advantages and disadvantages of the respective geometrical methods of estimating areas and volumes. I refrain from discussing the estimation of weights in a ship design, as it is an arithmetical rather than a mathematical matter.

The calculations of stability—coming now to that—have undergone great improvement in this country since the commencement of our work as an Institution. In his paper of 1860 Dr. Woolley sketched in clear outline the work of Dupin giving the characteristics and relationships of the various loci of the centres of buoyancy, the centres of gravity of the water-line planes cutting off equal displacements, &c. In order to acquire a just conception of the progress made since, we must carefully bear in mind that we have had no new elements and no new principles to deal with since 1860; all that could be done was to present the old materials in new aspects or in new combinations, having due regard to the improvement of the practical calculations; for in every ship, or ship-like floating body, detailed calculations, or equivalent mechanical experiments, must be made to suit the particular case presented, if they are to be more than approximate. It is only in theoretical cases, such as those of bodies of symmetrical form, or in mere approximations, that exact calculations can be dispensed with.

I should like, before advancing with this section of my paper, to say that there are some difficulties of definition and nomenclature in this matter that it is necessary to take note of. I will mention them very briefly. In this country it was long understood that, for an ordinary ship, floating in the ordinary manner, there was but one "metacentre," viz., that due to a slight inclination from the upright. It was necessarily situated in the vertical centre line of the ship. Of late years some persons have fallen into the habit of speaking of a large number of other points as metacentres, while the French also designate by the same word a large number of other points, theirs being quite different points from ours. Let me illustrate this, for confusion in respect of elementary matters is a very bad form of confusion. The annexed simple diagram, Fig. 1 (page 76), illustrates both the error we commit, and the difference between French and English practice. In this figure, M is the point which we all agree to call the metacentre, and is a metacentre proper. B is the corresponding centre of buoyancy in the upright position; B_1, B_2, and B_3 are other centres of buoyancy at successively greater angles of inclination. The lines $B_1 L_1$, $B_2 L_2$, $B L_3$ are radii of curvature of the curve of buoyancy at the points B_1, B_2, and B_3 respectively. M_1, M_2, and M_3 are the points in which these radii cut the original vertical axis of the ship B M. Now the French call the points M_1, M_2, and M_3 (and all other such points) metacentres, but connect each such point with the angle of inclination to which it corresponds, so that no misunderstanding need arise. In this country some writers call the points L_1, L_2, L_3, metacentres; but they clearly are not so,* and cannot be so called without confusion in dealing with ship calculations. They are, no doubt, obtained, like the

* "This term is, we think, open to the very serious objection that it is not a metacentre—*i.e.*, a limiting position of the ship's centre of gravity, in the true sense of the word, as separating stable from unstable or neutral equilibrium. It is very likely to be misunderstood by the unlearned or the sciolist, and seems really to have misled."—Dr. Woolley in "Naval Science," Vol. III. p. 441.

metacentre itself, by the intersection of two closely adjacent lines through which the buoyancy acts upwards; but in dealing with ship calculations it is well to keep the original upright axis of the ship in mind, and to call nothing a metacentre that is not situated in it. The curve through the points L_1, L_2, L_3, is really the locus of the points in which a series of these closely adjacent lines of upward pressure intersect, that locus being, as known to most of you, the *evolute* of the curve of buoyancy. This evolute is sometimes spoken of as the "metacentric evolute." In my writings on the subject I have, for the sake of clearness, called all such points as L_1, L_2, and L_3 "pro-metacentres," as they serve, for some limited purposes, at larger inclinations, the same

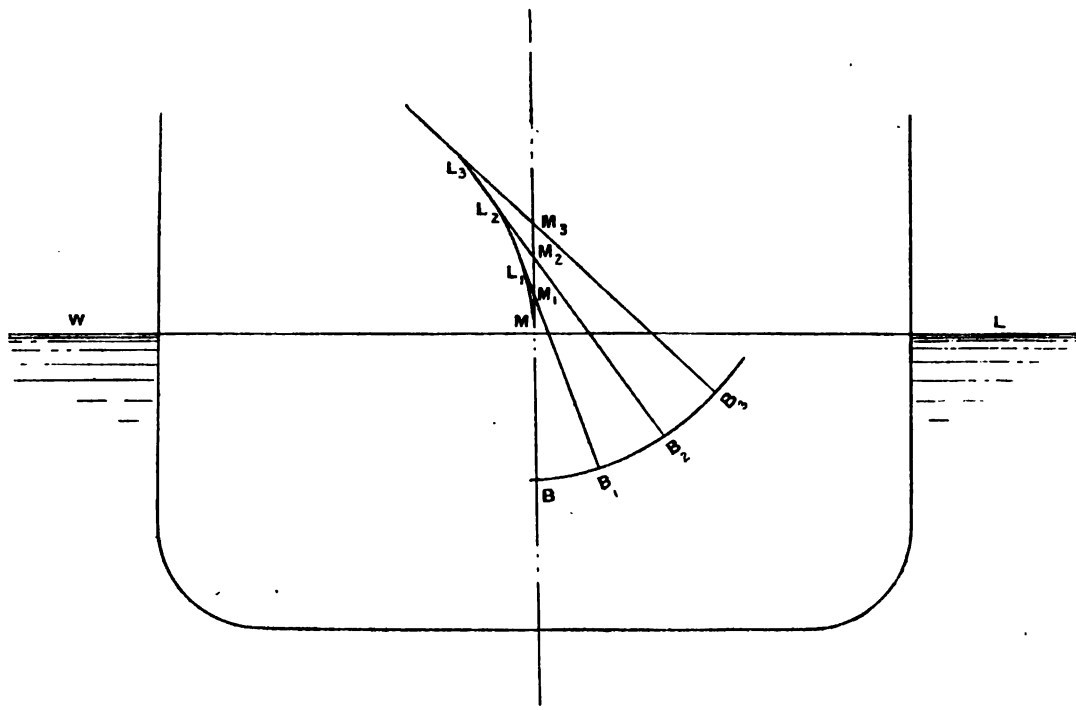


FIG. 1.

ends as metacentres serve in the upright position; and the curve M L_3 I call, accordingly, the "curve of pro-metacentres." Such points as M_1, M_2, and M_3 (the French "metacentres at given angles") have been sometimes called among us "shifting metacentres," but this designation is not wholly free from objection. In strictness there can be but one metacentre for one draught of water; but these points have, at any rate, the merit of lying, all of them, in the vertical axis of the ship, and reasonable care in the use of the words "shifting metacentre" may avoid any very great confusion. I fear it is too late to abolish the use of Bouguer's word "metacentric" (*métacentrique*) as a designation for the evolute of the curve of buoyancy, or to get rid of its other appellations, "metacentric evolute" and "metacentric curve," although

the fact of the metacentre being a point upon this curve is the only justification—and a very poor one—that I can find for these designations.* Against one thing, however, I have protested, and do protest, viz., the calling of this curve a "curve of metacentres," as some writers have done. It is no curve of metacentres, properly so called, and that designation must be reserved for a curve constructed to represent the relative positions of true metacentres at different draughts of water, which is an altogether different matter.

Very serious objection has been taken by some scientific writers, notably by Professor Osborne Reynolds, to the confusing use which undoubtedly exists of the word "stability" itself. It has been pointed out that the word "stability" is often employed as the equivalent for the length of the righting lever, known generally as G Z, or for this length multiplied by the weight of the ship. Professor Reynolds, at

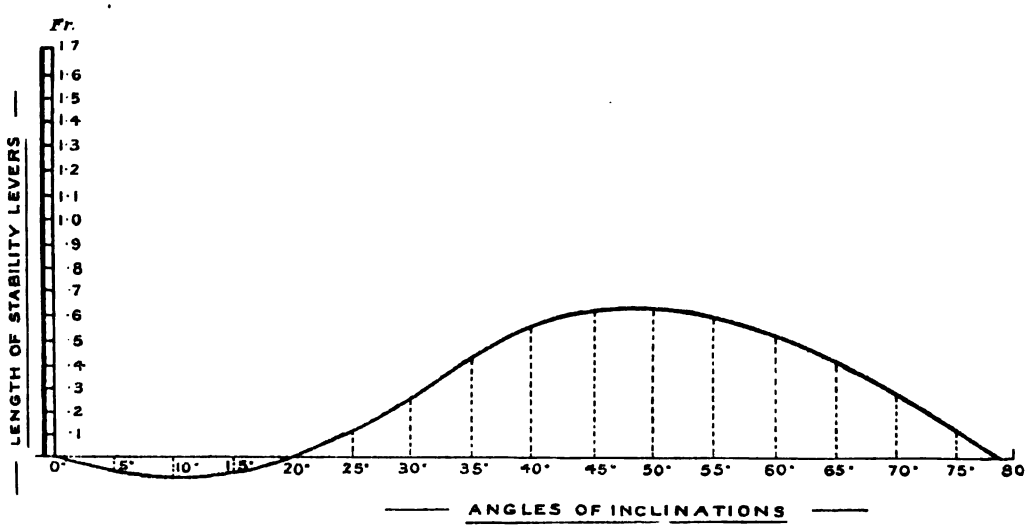


FIG. 2.

the British Association a few years ago, said: "In recent literature on naval architecture the term stability occurs over and over again in the sense of righting moment, and this under circumstances where the context shows the meaning to be incompatible with any meaning that can be given to the word, for stability must refer to some position in which the ship is stable"; and he went on to develop this objection at some length, particularly pointing out, what is perfectly true, viz., that the righting moment exerted by the buoyancy at considerable angles of inclination is often found to

* I am, of course, well aware that Bouguer headed his fifth chapter "On More Extended Investigations in the Metacentres and the Curve Line which these Points Form when the Ship is Inclined," and that he calls the "metacentric evolute" the *métacentrique*. But Bouguer himself fell into error in connection with this matter, and it is not desirable either to create, or to perpetuate, so confusing a nomenclature.

be effective, not in restoring the body to an upright position, but merely in restoring it to some other less inclined position, in which it will remain if left free to do so. The truth of this is well known to most of those present, but it may be as well to give the curve of stability of an actual ship illustrating the case, Fig. 2 (page 77). This ship has a negative metacentric height of 6 ins., and she lolls over 20° before she begins to acquire an opposing moment. From 20° to nearly 80° she has a righting moment of precisely the same kind as any ordinary ship; but this moment only returns her *toward*, and not *to*, the upright position. Again, when we speak of righting levers and righting moments (which are but conditional measures of rotating forces) as identities with or equivalents of "stability," we reach the anomalous position of having, even in a ship of very great stability in the popular sense of the term, no stability at all when she is upright, or, as in the case just illustrated, none at all when she lies free and at rest at 20° of inclination. There is nothing in all this which presents any difficulty to the expert naval architect; but, as I have lately had frequent occasion to take note of very incongruous views and conflicting expressions of opinion arising from these troublesome anomalies, and have observed judges, counsel, mercantile marine officers, and even members of a Parliamentary committee, greatly puzzled by them, it seems to me most necessary to put people on their guard against them. I would even suggest whether we might not, in view of the growing importance of the subject, appoint an International Committee for arranging, and, so far as practicable, settling, both improved definitions and an improved nomenclature for this much cultivated branch of naval science.

I now go on to say that the progress made in the development of the doctrines and of the practice of stability since 1860 has been so extensive that, although I endeavoured to condense my work, this one subject covered nearly 400 pages in a volume which I devoted to it ten years ago. In educational establishments, in the practice of the Admiralty and of the mercantile shipbuilding yards, on board ship, and in shipping institutions, the study of stability in its most recent forms has exceeded all that could have been anticipated. Three successive incidents contributed so strongly to this result that, although I was personally connected with two of them, I feel constrained to notice them.

I refer, first, to the investigations which led to the production of the now familiar "Curve of Stability." In this country, certainly, the practical need for detailed measurements of stability at large angles had not arisen in 1860, all ships being more or less high-sided, and, therefore, stable enough at comparatively large angles, even in the days when all ships were sailing ships.* But when we came to consider low-sided

* "In fact, so far as our knowledge extends, there seems good reason to believe that no consideration was given to the range of a ship's stability, and that, until four years ago, no calculation had been made of the stability of a ship with the upper deck partially immersed."—Messrs. White and John "On the Calculation of the Stability of Ships," &c., in Transactions I.N.A., 1871.

sailing ships the matter assumed a wholly different aspect; and when in 1867 or 1868 proposals to cut down certain of H.M. ships to low-freeboard sailing ships were made, it became my duty, as Chief Constructor of the Navy, to look seriously and responsibly into them. I accordingly determined to have the stability of a particular ship (which had been named for this treatment) calculated at 5° inclination, and at successive intervals of 5° each, until the stability disappeared; and this constitutes the first of the three incidents mentioned. Mr. (now Sir Nathaniel) Barnaby was desired to see these calculations carried out, and to submit to me the results. Mr. W. John was the member of the Admiralty Staff chosen by Mr. Barnaby to make the calculations in detail, and when Mr. John had obtained the quantitative results it occurred to him to embody them in a diagram, with angles of inclination for abscissæ, and the lengths of the righting levers (G Z's) set up as ordinates at their corresponding angles.* This diagram was brought to me with the other results, and in April, 1868, I submitted to this Institution a paper "On the Stability of Monitors under Canvas," in which I gave the results, illustrating them with the said diagram, which subsequently formed Plate VI. of Vol. IX. of our Transactions. The diagram was afterwards spoken of as a "curve of stability," and thus the first "curve of stability" (as the term has since come to be understood among us) came to be constructed and placed before this Institution and the world. In their joint paper of 1871, Sir William White and the late Mr. John said of my paper of 1868:—"It showed conclusively that instability would occur in such (low-freeboard) vessels at a very moderate angle of inclination, and illustrated the contrast, as regards stability and safety, existing between rigged ships with high freeboard and those with low freeboard. . . . This paper did not succeed, however, in impressing members of the profession with the necessity for more complete calculations of stability, and the subject remained in comparative obscurity until the loss of the *Captain* forced it into painful prominence."

This loss of the *Captain* was the second incident to which I referred above, and it will now be admitted that Messrs. White and John were true prophets when they added: "It does not seem too much to say that this great calamity will mark an epoch in the

* Mr. John afterwards mentioned to me that he thought it so natural to record the results in a diagram, just as we record so many other measurements varying from point to point (for example, in calculating the volume of displacement by the ordinary rules, having calculated the areas of certain bounding sections, we make these areas the ordinates of another curve) that he constructed the diagram quite incidentally, and without even intending to submit it; but afterwards considered that I might find it convenient for reference, and consequently sent it forward, together with the figures I had called for, and of which it was a mere reflection. In fact, at a discussion in this Institution in 1884, Mr. John himself referred to these particular calculations, explained the original method by which he effected the measurement of the righting levers at successive large angles of inclination, proceeding beyond the immersion of the edge of the upper deck, and added:—"Having obtained them, and wanting to find out where the stability really vanished, it was the most natural thing in the world to form a curve out of the spots, and that became the now well-known curve of stability."

science of naval architecture." The paper of those gentlemen was one of the early and great contributions to the science of the new era; and another, and very valuable one, was made at the same meeting by Sir Nathaniel Barnaby on the relative influence of beam and freeboard on curves of stability, and both the results of his investigations, and the illustrative diagrams attending them, presented a most impressive view of the dangers of low freeboard when associated with a considerable spread of canvas.

It unhappily required a further incident, and another calamity, to open men's eyes to the very opposite danger, viz., that of ships capsizing at light draught. In 1883 the *Daphne* capsized on the Clyde during launching, and I was sent down by the Government to inquire and report upon the accident. The inquiry developed several facts which showed how much need there was for large extensions of stability calculations. It proved that ships of modern type are sometimes characterised when floating light by very abnormal deficiencies of stability in inclined positions. The *Daphne* herself possessed not only small stability, but a slow growth of it with increase of inclination. No curve of stability at the launching draught had at that time been calculated for any ship. Sufficient initial stability had been always regarded in ordinary ships as a guarantee of sufficient stability at all angles. Even the highest of our authorities at home had assumed this to be the case. All this proved, however, to be quite erroneous.

It has therefore happened, since we commenced our work as an Institution, that novel professional exigencies have laid upon us the necessity of guarding equally against the dangers both of *deficient* and of *excessive* immersion, and have consequently greatly enlarged the boundaries up to the limits of which the designer has to work. It will be seen that naval architects have promptly cultivated the enlarged field.

One consequence of the earlier incidents above mentioned was to excite the educational authorities to special exertions. At the Royal School of Naval Architecture —of which the high officers of the Admiralty were in chief control—Sir Nathaniel Barnaby first, and his successor in office, Sir William White, caused the students to apply themselves to the work of carrying out elaborate calculations, alike for the purpose of applying received methods to the estimation of the stability of specific ships or designs, and for the further purpose of testing, or giving effect to, novel methods. A principal of that school, the late Mr. Merrifield, devoted himself to the production of methods of approximation for the ready estimation of stability, taking, as a fundamental assumption, the assumed identity of the curve of buoyancy with a conic. The labour of finding the true position of the inclined water-line was got over by constructing from the ordinary water-lines a mean section of the ship, and making out a scale of displacement for this section at various immersions. The radius of curvature was found by finding the moment of inertia of the water-line plane of the given inclination,

and dividing it by the volume of displacement, as usual. Professor Macquorn Rankine improved upon this by assuming that the curve of buoyancy is not a conic, but the involute of the involute of a circle, the " metacentric evolute " being thus assumed to be an involute of a circle. Dr. Woolley, again, improved upon Rankine's system, while employing the same assumption as he to the extent of assuming that the portion of the involute of a circle, lying between any two successive radii of curvature, practically corresponds with the corresponding portion of the evolute itself. He employed a succession of such evolutes, which were calculated in their *ensemble* to coincide fairly with the metacentric evolute. The method was not founded on the principle of finding the radius of curvature in any extreme position, but on that of obtaining a succession of radii at given finite angles. Although it was found that, applying the system to a prismatic body, and taking the angular intervals to be 5°, the error was only about two per cent., Dr. Woolley nevertheless considered all these approximate systems, although fascinating as geometrical problems, so inferior to exact methods, that he readily abandoned his own as well as the others in favour of M. Reech's more perfect system, of which I will presently make mention.

In speaking briefly of Admiralty practice in this matter, subsequent to 1860, I must do Mr. Barnes, one of our most capable professional Vice-Presidents, the justice of saying that more than one of his great contributions to the advancement of our stability work was made without the stimulus of any precedent calamity. At our Second Annual Meeting (1861) he presented us with a new method of calculating the statical and dynamical stabilities, which was so clear, so sound, and so practical, that it displaced at the Admiralty all other methods. Sir William White, ten years afterwards, spoke of it as affording the first means which we possessed of readily effecting the necessary calculations. In 1864 the same authority, Mr. Barnes—who has always brought a rare combination of sound mathematics and strong practical sense to bear upon such questions—gave us another stability paper, in which he proposed the application of the longitudinal metacentre to the calculation of changes in a ship's trim. He also was the first person, I believe, to devise and publish the " metacentric diagram," of which I will presently speak.

The later developments of Admiralty work have been most remarkable. In his paper of 1871 Sir William White, with Mr. John, gave us a most valuable account of such modifications and extensions of Mr. Barnes' method as modern conditions had made desirable, and of the detailed work of carrying them out; and proceeded, with a courage which their experience justified, to apply to the illustrious Dupin one or two of those corrections which the theorist generously allows the practical man the exquisite pleasure of discovering. A little later (in 1878) Sir William White gave us a most instructive discourse upon the geometry of the " Metacentric Diagram " introduced by Mr. Barnes, and I have been gratified, on referring back to this paper, to find how

skilfully Sir William White avoided that confusion of language into which a less expert investigator might easily have fallen. For here we have a case of those "metacentric curves" which are wholly different from the others to which I have previously referred as bearing precisely the same designation. While those previous curves, although called metacentric curves, are nothing more, as we saw, than curves of pro-metacentres, here, in Sir William White's paper, we have curves of actual metacentres to deal with. Such metacentric diagrams have to do with different draughts of water, and are employed to show the variations in the metacentric height at those different draughts. I much wish that time allowed me to do justice to this paper, and to its applications to ships both of war and commerce. The manner in which theoretical views and actual calculations for ships are combined for the improvement of our operations, presents in Sir William's paper an example of the best possible professional work. All that I can allow myself to do, for the sake of clearness, is to give the following brief description of a "Metacentric Diagram," and how it is formed.* A series of horizontal lines, $w'\ l'$, $w''\ l''$, &c. (Fig. 3), are drawn at heights representing, on some convenient scale, the various mean draughts of water at which the positions of the metacentres and centres of buoyancy have been calculated. An oblique line, $o\ p$, is drawn across these horizontal water-lines, inclined to them at an angle of 45°; and from the points at which this line intersects the respective water-lines are drawn vertical lines, upon which are set off, on the same scale as before, the distances down of the centres of buoyancy, b, b', b'', &c., below the corresponding water-lines, and from these centres of buoyancy are set up the corresponding metacentres, m, m', m'', &c. A fair *curve* passed through all the metacentres so obtained, and another passed through all the centres of buoyancy, will respectively be a curve or locus of metacentres, and a curve or locus of centres of buoyancy. It is often found convenient to have the scale of displacement represented on the same diagram. For this purpose a vertical line is drawn through the intersection of the oblique line, before mentioned, with the water-line corresponding to the load-draught of the ship. From this vertical line are set off, on any convenient scale of tons, in a horizontal direction, the calculated displacements at the draughts represented by the water-lines before used; a fair *curve* passed through

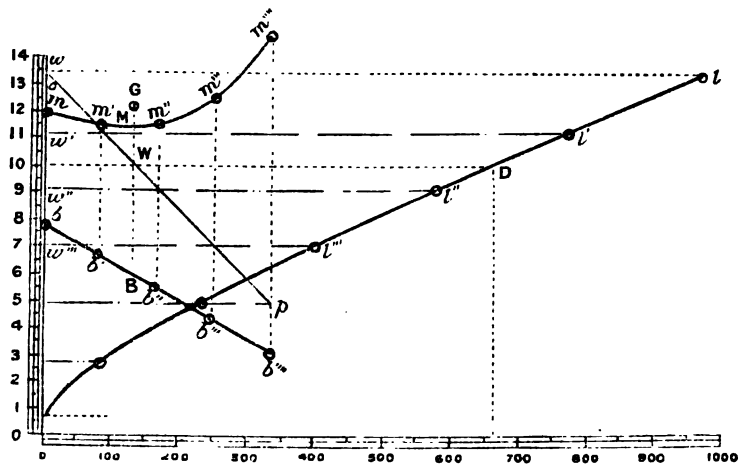


FIG. 3.

* From "Stability of Ships," p. 82.

all the points thus obtained is the curve of displacement, as shown in Fig. 3. From this complete diagram the position of the metacentre can be obtained for any given displacement, draught of water, or position of centre of buoyancy within the given limits; and in like manner, for any given value of either of the latter, the other corresponding positions can be obtained.

It will be seen from this description that this metacentric diagram deals only with variations of draughts of water, whereas the curve of pro-metacentres deals only with changes of inclination.

Another highly competent and distinguished naval architect, Dr. Elgar, one of our Vice-Presidents, introduced a still more ingenious mode of exhibiting stability elements in a diagram. This was communicated to the Royal Society, and possesses the advantage of giving in one diagram the variations of stability for variations both of draught of water and of angle of inclination. These cross curves of stability, as they are called, are formed from curves of stability (of the ordinary kind) made for the light, load, and two or three intermediate draughts of water. The measures of stability at the respective draughts, at one given angle, are made the horizontal ordinates of a vertical curve which may be described as a vertical curve of stability at that particular inclination. A similar vertical curve is drawn for each other angle of inclination. The *ensemble* of these vertical curves is the complete diagram. By employing these curves in their turn, as furnishing measures of stability at different draughts and inclinations, the number of ordinary curves of stability may obviously be increased to any desired extent.

While the Admiralty stability work has been extending, beyond what I have shown, not a few private shipbuilding firms have pursued a similar course, developing in some instances new methods of investigation suited to the special requirements of mercantile ships. I can cite only an example or two. Messrs. Denny Bros., of Dumbarton, followed up the cross curve system of Dr. Elgar, or possibly worked it out independently for themselves, with the aid of a group of scientific assistants, making large and ingenious use of the mechanical integrator for the purpose. They employed numerous draughts of water, and found it preferable, under their system, to calculate the cross curves first, and take from them the usual curves of stability, for the given draughts of water. The late Mr. Jenkins likewise worked with advantage at this subject, and facilitated, by a particular investigation, the determination of the exact depths of immersion at which the righting moment attains its maximum and minimum values.

Another example of a like kind is furnished by Mr. Inglis, of Pointhouse Shipyard, Glasgow, a much-respected officer of this Institution, who applied the metacentric diagram to the varying conditions of merchant vessels in a novel and valuable manner. Mr. Inglis was good enough to favour me, for use in my book on Stability, with the

diagram, Fig. 4, which exhibits the system he pursues. The horizontal scales at the bottom of the figure are two in number, the one being a scale of feet for showing the height above the floor and ceiling available for the cargo, the zero being at the top of keel, and the cargo space commencing somewhat more than 2 ft. above it; the other being a scale, also in feet, of draught of water, and the stowage of cargo, on the assumption that the cargo is of such a specific gravity as to bring the ship (when filled with it) to her designed load draught, and is poured in, so to speak, in such manner as to keep its surface always level. The upright scales are also two in number, the one being a scale of cargo capacity in cubic feet, from which may be read off the quantity of the homogeneous cargo on board at any time by means of the "curve of capacity" to be presently mentioned; and the other being a scale of feet, set off above the top of the keel, serving as a scale of heights for centres of gravity and metacentres. The curve A A is the "curve of capacity" before mentioned; by taking any point upon this curve, and projecting it horizontally upon the vertical scale of capacity, the number of cubic feet on board (from which the number of tons which it weighs may be inferred, there being allowed in this instance 58·5 cubic feet per ton of deadweight, or a specific gravity of ·615) can at once be seen; while projecting the same point vertically downwards upon the horizontal scales, the corresponding depth of cargo in hold, and the corresponding draught of water of the vessel can be read off. The curve marked G C exhibits, from point to point, the heights of the centre of gravity of the homogeneous cargo, these heights being read off from the vertical scale of feet at the side of the figure; the curve G G represents the heights of the common centre of gravity of both the ship and the cargo, and the curve M M represents the heights of the metacentres (within the requisite limits) both of these latter sets of heights being read off from the same vertical scale at the side of

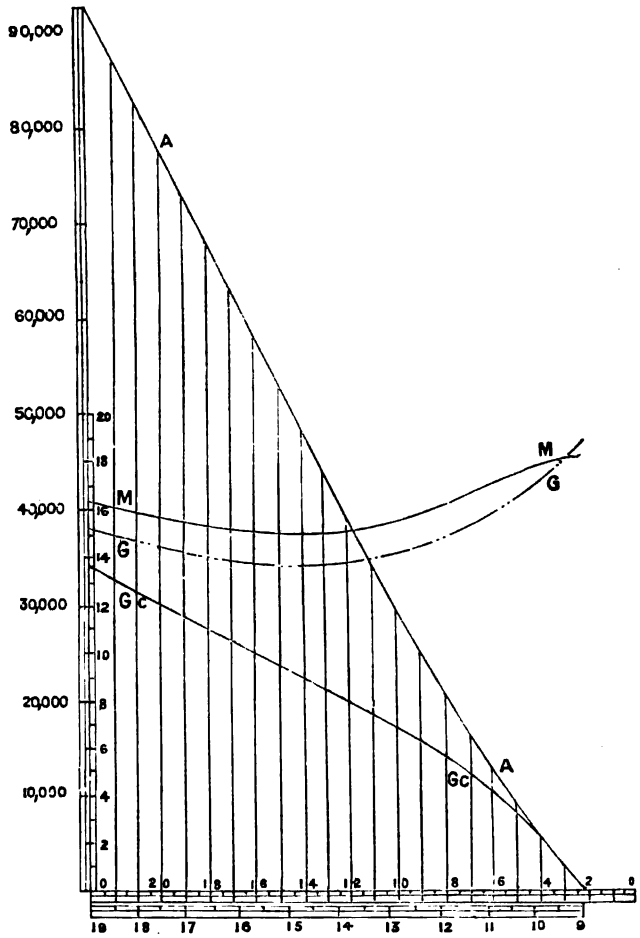


FIG. 4.

the figure. A comparison of the curves, G G and M M, at any point, exhibits the measure of metacentric stability which the ship possesses, with the corresponding quantity of homogeneous cargo of the given specific gravity on board. In arranging this diagram, and making the assumptions as to specific gravity of cargo and stowage on which it rests, it is presumed that the worst case which need arise is provided for, because the cargo is the lightest possible compatible with its being homogeneous, and yet bringing the ship down to her load draught, observing that its assumed specific gravity (·615) is less than one-half that of coal. If any part of the cargo be heavier than the homogeneous cargo here considered, it may be inferred that this heavier part may be placed low, so as to bring down the centre of gravity and add to the stability.

In many other private shipbuilding firms similar uses have from time to time been made of recent developments of the theory of stability, Messrs. J. & G. Thomson, of Glasgow, and Mr. J. H. Biles, their technical adviser, standing eminent among them, both on account of the completeness of the work done, and of the liberality with which they have allowed the publication of the results. Mr. Martell, at Lloyd's Register Office, has innumerable operations for testing the stability of merchant steamers carried out, and many of them made public with the enlightened sanction of Lloyd's Committee.

Turning our attention for a few moments to the labours of non-British professional men, I may be permitted to remark that, while recognising, I hope fully, the great anticipatory labours of Bouguer, Dupin, and others, and in no way seeking to claim for our Institution any credit on account of French progress—for if credit there be it must be brought to us from abroad, and there may be none due—it is nevertheless true that, since the establishment of this Institution, *i.e.*, since 1860, there has actually been much work done in France in the way of applying geometrical principles to the actual calculations of ship stability. In 1863, Monsieur G. Dargnies, a former pupil of the French Naval School, and, at the time mentioned, naval architect to the *Messageries Impériales*, made stability calculations for angles of 10°, 20°, 30°, and 40°, and for several draughts of water intermediate between the light and load draughts. His process was essentially French. By calculating the several radii of curvature of the curve of buoyancy approximately, and laying down by means of these radii, and by a tentative process, the "metacentric" (or evolute of the curve of buoyancy), he dispensed with the calculation of the centres of buoyancy. A further interesting part of the work of M. Dargnies consisted of means for verifying the values obtained for the metacentric radii at the various inclinations and displacements. These were obtained by the use of two sets of curves; one, corresponding to a constant displacement, having for abscissæ the angles of inclination; while the other was for a constant inclination with draughts of water for abscissæ, the ordinates in both cases consisting of the corresponding metacentric radii. These curves indicated the general forms and transformations of the

evolutes for the region comprised (light to load draught), the second of the curves enabling one to draw immediately the evolute for any draught within that region.

M. Reech,* early in 1864, having had the calculations of M. Dargnies submitted to him by the author, saw reason to suppose that they could be improved upon, and suggested a system of operation of more convenience, and determining more exactly both the curves of buoyancy and the metacentric evolutes of a vessel. His first improvement upon the paper of M. Dargnies was a repetition of a method included in his revised course on the Stability of Floating Bodies given at the Paris Naval School.

M. Reech went on to give another, and, as is certain, a better method of determining the metacentric evolutes of a vessel, because it set the inquiry free from the necessity of dealing with a single prescribed draught of water, and gave results in a form available for such variable draughts of water as it might be necessary to deal with. His method rests upon the fact that, if we consider only inclinations round a longitudinal axis, and therefore planes of flotation perpendicular to the vertical transverse plane of the ship, any plane whatever will be fully determined by the angle of inclination θ which it makes with the original horizontal plane of flotation, and by the volume V which it cuts off. All the quantities dependent upon the volume cut off by any such plane are functions of the two independent variables, θ and V only. Nothing can be either more sound or more elegant than the manner in which the method is mathematically developed in the original *Mémoire* of M. Reech.† The late Dr. Woolley, writing to me in 1884, said, "Reech's method is so simple, and founded on so well-known a property, that it seems wonderful that it never occurred to anyone before. . . . . I am convinced that if ever the present system of calculating stability in this country be superseded, it will be by Reech's, or some other founded on it, and equivalent to it." It was promptly adopted in France, and in 1870 M. Risbec —a well-known cultivator of this field of science—prepared a Calculation Form for its application, stating that the new method had made it practicable to carry out all the calculations of a ship's stability (with the assistance of tables of squares and cubes) as easily as calculations of displacements were carried out. I regret that the scheme of this paper does not admit of my giving here even a sketch of his methods.

It is not possible to leave wholly unnoticed the exhaustive treatment of statical stability and of its calculations worked out by M. Daymard, who has done us the honour of so frequently attending our meetings. M. Daymard has stated that it was while pursuing certain investigations of his father-in-law, the late M. de Ferranty (who himself laboured with much success at the simplification of calculations of

* A former most able and distinguished Directeur de l'Ecole d'Application du Génie Maritime.

† The only English translation of this known to me is that published at pp. 256—263 of my "Stability of Ships" (Charles Griffin & Co.).

stability extended to large angles of inclination) that he conceived the idea of joining the extremities of the arms of righting levers (corresponding to like angles of inclination, but to different draughts of water), by continuous lines, starting on the temporary assumption of the centre of gravity being identical with the centre of buoyancy. The curves thus drawn—identical in principle, as will be seen, with Dr. Elgar's cross curves of stability—he called *pantocarènes isoclines*, and he saw, as Dr. Elgar saw, that he could obtain from them, with exactitude, and for all possible cases, the usual curves of stability. Having obtained the means of determining the two extremities of each *pantocarène*, and of calculating directly, and in a mathematical manner, as many intermediate points as he wished, he prepared a sample table of calculations by means of which he could, "in a comparatively short time (about 40 hours) arrive at the complete representation of these curves for a ship, at intervals of 10°, from 0° to 180°, and for all draughts of water, and consequently at the entire solution of the problem of the stability of a ship." It is needless in this case to enter into further particulars, as the system was completely described in all necessary detail by M. Daymard himself in our 25th Volume (1884).

The limits of this paper do not admit of my doing full justice, or anything like full justice, in respect of statical stability, to even our French friends alone, and still less to the valuable labours of numerous other foreign investigators. It would require more time, and probably more skill, than I have at my disposal, even to apportion the effective progress made in the studies of stability and stability calculations to the respective countries who have shared in the production of it, and much more to apportion it to the respective investigators in each country. To do either would be to perform the double work of distributing awards of merit, first, in respect of the geometrical aspects of the subject; and secondly, in respect of the accuracy, facility, and economy (of time) which the various improvements in actual calculations have brought about. I ought to say, however, to prevent possible misapprehension, that, bearing in mind the respective bents of the French and British minds in dealing with a subject of this nature—the latter looking mainly to the final result to be effected by such calculations, and the former, although looking also to that result, nevertheless allowing itself frequent and splendid excursions into ideal geometrical regions—there seems to me no good reason to doubt that both France and Britain have been well served.

It has to be acknowledged, of course, that in all the calculations for statical stability the assumptions involved, if not wholly imaginary, are so in a large degree. For example, the usually assumed statical position of a ship inclined through a given angle in still water, subject to a considerable righting force, is admittedly of that character. Nothing but an external applied force could bring her into such a position, and any such applied force, with some possible exceptions, would certainly alter

her immersion. I mention the matter, not because I regard it as impairing the results of our stability calculations (for the imagination is a faculty of supreme necessity to the pursuers of science everywhere, and in mathematical work that which is most purely imaginary is often the most true); but because it is a matter which has to be borne in mind in approaching the dynamical aspect of stability, and points to the desirability of keeping continually in view the fact that all the ultimate problems of stability are necessarily dynamical problems. A ship at absolute rest in still water, could one exist, with no disturbing force whatever acting upon it—no air of heaven even breathing on it—would, of course, exert or elicit absolutely no stability in the technical sense of the word. To bring stability, or the exercise of a righting force, into play, disturbance is obviously necessary. In an investigation of Mons. M. E. Guyou, of the Navy of France, entitled "Théorie Nouvelle de la Stabilité de l'Équilibre des Corps Flottants" (which falls within the period under review), the author lays it down, with some insistence, that the problem of stability is necessarily and purely a dynamical problem. He says we cannot speak of an actual floating body being in equilibrium in any other sense than that, being made to undergo a small disturbance, it will, after a series of oscillations, necessarily return to its primary position. There is nothing, of course, really novel in this view — nothing novel, I mean, to those who have mastered the principles of the subject; but we have also to consider the nautical and outer world. There is very much novelty, and very much beauty, too, in the manner in which M. Guyou pursues his inquiries, dealing mainly with a body afloat in a vessel containing water, and discussing the movements and conditions of both the fluid and the floating body, and their relations to each other, on perfectly sound dynamical principles. I need hardly remind members of the Institution that M. Bertin, in his valuable "Notes on Waves and Rolling" passes by an easy transition from the statical to the dynamical operation of a ship's righting forces; while MM. Risbec and Duhil de Benazé treated the subject from the point of view that all the work done by the oscillations of a ship proceeds solely from the vertical displacements of the centre of gravity and the centre of buoyancy. I may add that long before either of the above gentlemen entered the field, and before even our own lamented Vice-President, Canon Moseley, brought forward his famous exposition of dynamical stability—which he fondly supposed to be perfectly novel—the question of dynamical treatment received recognition and consideration from M. Moreau, a former Professor of the French *École Royale du Génie Maritime*. Professor Moreau, in 1830, published at Brest a work in which the dynamical view of the question was clearly set forth. It was, however, only small oscillations that Moreau considered, and he employed his results only for obtaining maximum and minimum values of the height of the centre of gravity. It was no great anticipation, therefore, of Moseley's much larger and farther-reaching investigations, and, such as it was, was unknown to him; for, in his Royal Society paper of 1850,

in which he first made his system known, Canon Moseley said: "I cannot find that the question has before been considered in this point of view, but only in that which determined whether any given position be one of stable, unstable, or mixed equilibrium, or which determines what pressure is necessary to detain the body at any given inclination from such a position."

The calculation of dynamical stability for still water conditions presents no difficulty. Leaving aside for the moment all consideration of external disturbing forces, and dealing only with the smooth water case, no room for difference of opinion exists. It practically resolves itself into a question of the amount of work done in inclining a ship from one given position to another, and this can be ascertained by multiplying the weight of the ship into the vertical distance through which the centres of gravity and buoyancy have separated during the inclination. If, again, we take the ordinary curve of statical stability (G Z's) for the ship, and set off upon it the angles before and after inclination, the *area* of the curve between the ordinates at those points will give the same thing, or rather be proportional to it (as the weight must, of course, enter in as a multiplier); for the area of the curve between those ordinates will represent the sum of the infinitesimal items of work done from point to point. By calculating all such areas, and making them ordinates of a new curve, a curve of dynamical stability is obtained.

It is when the effects of winds and waves are brought in that the difficulties commence, and it cannot, I think, be said that the problem has yet received its complete and final solution. Even the mode of accounting for the inclining force of the wind upon sails, by graphically setting apart portions of the curve of stability for the wind's consumption, so to speak, has not always been similarly dealt with even by competent investigators. When wave-action is likewise brought into account, the differences between them have been increased. In fact, one ingenious and singularly clear-headed naval architect took exception to the parcelling out of the curve of stability into divisions respectively appropriated to the effects of the wind and of the waves. He much preferred to take them both into account by assuming the ship under sail to be rolling in the worst waves she is likely to encounter, and then struck by a squall at that part of her roll at which the force of the squall would be most dangerous.

It must be acknowledged that this Institution has been most fortunate in having had unfolded, under its auspices, in a remarkable manner, the mathematical theory of a ship's rolling among waves. So early as at its second meeting the late Mr. Froude, in an extempore address, afterwards brought into written form, expounded to us his novel and beautiful theory of rolling, which has formed the basis of all that has been done since in this country on this subject. That address excited the greatest possible

attention, and, although received with some doubt and distrust at first, even by our most mathematical colleagues, has taken its permanent and lofty place in the science of our profession. It is quite true that Bernouilli, a century before, had written a most remarkable "Mémoire," and obtained for it the prize of the French Royal Academy of Sciences, founding his investigation upon the assumption that the oscillations of waves will prevail over those of the ship, so that the "periods" of both will come to be identical, the *amplitude* of the rolling only being dependent upon the ship's natural time of oscillation. He initiated the idea—so much resorted to since—of assimilating the motion of the ship in waves to that of a pendulum whose natural oscillation was disturbed by an external force recurring periodically. He applied the formula for the pendulum to the case of the ship, and in some degree anticipated the point which Mr. Froude so much and so properly insisted upon, viz., the danger that may result from an approximate equality between the natural time of oscillation of the ship and the wave period. But the paper of Froude was a wholly novel and noble piece of scientific work, and elicited from the late Canon Moseley, the only Englishman of that time who had worked publicly at dynamical stability, his highest approval, as showing "that a great harvest of valuable results is to be reaped from the mathematical discussion of the more profound problems of shipbuilding science."

Mr. Froude's paper of 1861 was followed in 1862 by a most remarkable contribution concerning it from a gentleman recently deceased, my old friend and colleague at school and at the Admiralty, Mr. J. B. C. Crossland—a man second to none, whom I have known, in the clearness and power of his mind when applied to scientific objects; and yet so reluctant to accept publicity in any form that I had the greatest difficulty in inducing him to write his paper, and only succeeded in doing so by exercising official authority. Mr. Crossland's paper investigated the effects of stability upon a body afloat in water to which movements were imparted vertically, horizontally, and obliquely; and, in point of fact, confirmed Mr. Froude's principal views by wholly independent processes, and established those views upon even more general principles than Mr. Froude himself had set forth.*

From those early days onward, throughout the whole existence of the Institution, this question has been more or less under discussion, and only last year Mr. R. E.

* I would take the liberty of advising those who are interested in this branch of our science, and who have not gone back to our early Transactions, to refer to this paper of Mr. Crossland if they desire to master the primary principles which underlie this question. The late Mr. Froude, in the debate on this paper said: "Mr. Crossland appears to me to have followed out, on an independent line of thought, and in a thoroughly common sense and sound manner, a series of steps by which the fundamental laws of dynamics may be applied directly to the elementary conditions of motion belonging to wave surfaces, and to have pursued them further, in a manner not less original and interesting, into the more intricate and difficult conditions of complete wave motion—arriving, not indeed at a complete solution of the question, but at many very instructive views respecting it."

Froude read a most valuable paper upon it. There have been many labourers in this field, and among the most distinguished of them is M. Émile Bertin, of whose ability and industry our Transactions display abundant evidence. As recently as 1894, M. Bertin gave us a contribution upon the subject, in which, with engaging gallantry, he said that neither he nor others had thus far succeeded in greatly advancing the question of a ship's rolling upon waves that were not synchronous. At the Paris meeting of 1895, he dealt again, and with great fulness, on this aspect of the rolling question. The case of rolling on synchronous waves has, I believe we all admit, been pretty conclusively established; but rolling upon non-synchronous waves—and I am bound to say I generally find at sea that the search for any considerable series of synchronous waves is not very successful—presents us with a much wider and more debatable field. Mr. Froude, in his paper of 1896 just referred to, presents, with scientific frankness, many views different from those of M. Bertin, and conducts his argument with that finished skill and ample resource which make him so accomplished a successor to his illustrious father. The complexity of the problem is so great and undeniable that I feel it would be manifest folly to attempt to extract from it for your benefit even a clear statement of the situation. It is acknowledged by all that, as a rule at least, and so far as mid-ocean is concerned, the sea, if greatly disturbed, is disturbed in a confused and irregular manner. And therefore, as Mr. Froude most truly said last year, "the *net rolling* will consist of the superposition of the systems of rolling proper to the several component swells"; and, although he most ably analysed this net rolling into its component elements, I dare not further plunge you into the many perplexities of the subject.

It is only left me to say a practical word upon this question of rolling. Recent investigation and experience have shown that the large rolling of a ship at sea may be greatly checked by the use of bilge keels, and that for smaller angles of rolling the employment of free water in suitable chambers has a similar and considerable effect. One of our much-respected professional members of Council, Mr. Philip Watts, now of Elswick Shipyard, who, as long ago as 1871 wrote a masterly paper on the general question of rolling,* furnished us more recently (1883 and 1885) with papers on the use of water chambers, and incidentally of bilge keels, for reducing the rolling of ships, in which this subject is worked out with graphic illustrations. The use of water as ballast for merchant ships is, I fear, leading to some danger and loss, not because of any inherent defect in its use for this purpose, but because in applying it to the various objects of ballasting, trimming, and replacing fuel that has been consumed, more knowledge is required than is sometimes available, and more water ballast is needed than is sometimes arranged for. This, however, points not to defective scientific theory, but only to the desirability of extending scientific information.

* See the *Annual* of the Royal School of Naval Architecture and Marine Engineering for that year.

I have only space to remind you that in March of last year Captain A. Kriloff, Professor at the Naval Academy of St. Petersburg, brought before us a new mathematical theory of the pitching motions of ships on waves, which elicited, as it well deserved, the highest encomiums of our most competent critics. This discourse, with others just referred to, serves to show that the mathematics of the movements of a ship at sea are still undergoing yearly development, and that the Institution of Naval Architects in respect of this question may be proud of its past and confident of its future progress.

In his paper which forms the starting-point of my observations of to-day Dr. Woolley dealt but briefly with the question of resistance to the propulsion of ships; but in the short space devoted to it he took significant note of the unsatisfactory nature of the various theories of resistance existing at that time, refusing also to accept as in any sense conclusive the late Mr. Scott Russell's wave-line theory of least resistance. That theory was amply expounded by the author of it in later papers read during the same and the following session, with all the clean-cut thought, ready humour, and luminous exposition of which our departed friend was so great a master; but we have to acknowledge, I fear, that it never, in all its parts and as a complete theory, secured the assent of the great masters of naval science. It could not well have done so, even at that time, for reasons presently to appear, still less could it do so in the light that has fallen upon the subject since this Institution commenced its work. If there be any indisputable fact connected with the passage of a ship across the water it is certainly true that, from point to point, the ship has to place itself where the water has just been. This must be admitted; but it is impossible to doubt that a very false impression of the operation performed by a moving ship was created by treating this operation (as Scott Russell treated it in his most formal communications) as a case of ordinary "excavation." Taking a particular case, he said (Transactions I.N.A., Vol. I.), "This is an excavation of 16,200 tons of water in a minute; and this, therefore, is the measure of the minimum amount of excavation to be performed in order to clear the way of the ship." As if to remove all doubt or question, he added, "It is inevitable, and no human ingenuity can reduce it in quantity." The figures just given relate to a vessel of square section 36 ft. wide by 15 ft. deep; but were we to select, as we might from existing ships, the case of a vessel of about double these measurements, we should have a canal section four times greater, and the "excavation" per minute would be that of 65,000 tons of water, or 3,900,000 tons per hour, to be raised from the depth of the centre of buoyancy to the surface. This extravagant conception* of the fundamental work to be executed by

* "It is a point worth noticing here what an exceedingly small force, after all, is the resistance of a ship compared with the apparent magnitude of the phenomena involved. Scarcely anyone, I imagine, seeing, for instance, the new frigate *Shah* steaming at full speed would be inclined at first sight to credit, what is nevertheless the fact, that the whole propulsive force necessary to produce that apparently tremendous effect is only 27 tons; in fact, less than one two-hundredth part of the weight of the vessel."—*The late* W. FROUDE, F.R.S., *in his address to the Royal Institution, May,* 1876.

the propelling engines of a ship, although subject, as Mr. Scott Russell well knew and said, to qualifications, nevertheless lay at the basis of his theory of ship resistances. It is undesirable and unnecessary to pursue the subject here, as Scott Russell's proposition in no way enters into the theories of resistance which now prevail. I have only adverted to it because Dr. Woolley, far as he was from accepting it, after saying that we were then (in 1860) "as far as ever from a sound theory of resistances," went on to refer to Scott Russell's wave-line theory as one which "claimed" to effectually solve the problem! It therefore has to be taken into account as a theory falling within the period covered by this paper. It must not be inferred, however, from what I have said in depreciation of his theory that Scott Russell's investigations into this branch of our science were fruitless. On the contrary, they abounded with valuable facts and suggestions, and in his first paper, read to us in 1860, he drew forcible attention to a circumstance which every recent investigator must agree with, viz.:—that, from Sir Isaac Newton's onward, too many views of ship-resistance were inferred from experiments made with bodies situated entirely *under* the water. "A great error in inquiries of this kind has heretofore been committed," he said, "by resorting to phenomena of resistance of bodies entirely covered with water, and not only under the water, but entirely away from the surface; and by treating the results drawn from such observations as if they fairly represented the conditions of ships moving on the surface of the water." The truth of this criticism is now everywhere recognised.

It is not too much to say that, in most of its essentials, the theory of ship resistance has been completely changed since this Institution was founded. Were the work of "excavating" the water from the path of a ship the true measure of her resistance, it is obvious that a ship afloat on the surface with a given immersed section would experience less resistance than a ship of like section which was wholly and deeply immersed below the surface, because the ship floating at the surface would have to raise the spoil water, so to speak, a much less height than the other. But according to the now-accepted theory of resistance the deeply immersed ship would be relieved from much of the resistance which is found to exist at considerable speeds, and which is due to the production at the surface (by vessels floating there, and driven there at speed) of systems of waves which can only be directly produced at the free surface. Further, the late Mr. Wm. Froude proved that at low speeds the resistance to a ship is practically due only to surface friction. It is therefore proportional to the wetted surface, and not to the transverse sectional area of the vessel; and he very properly inferred from this that the excess of resistance which is experienced at higher speeds, and which grows with the increase of speed, is largely due to "wave-making."

It has here become necessary to outline, however briefly, the means by which we have reached the present state of the theory of resistances, as distinguished from its

condition in 1860, and for some time later. These means are to be traced in this country more or less specifically, and mainly, to the labours of Stokes, Lord Kelvin, Rankine, and the two Froudes. It was in 1870 that the late Professor Macquorn Rankine, profiting by prior investigations, presented to this Institution his version of the beautiful theory of stream lines, and stream line surfaces. These were given to us as the results of a mathematical investigation which was communicated in detail to the Royal Society. The subject had been in course of investigation by Rankine and others for several years previously, and the interim results, so to speak, had found their way, more or less, to the public; but in Rankine's paper of 1870, the results were brought up to date, and a strong impulse was thus given to the development of the modern theory of resistance. A "Stream Line"—one may say for the benefit of the uninitiated—is the path traced by a particle in a steady fluid current; and, therefore, when correctly depicted, a group of such lines will exhibit to the eye the motions of particles in different parts of a steady current moving round and past such an obstacle as a ship presents—the same motions resulting, of course, whether the ship moves through a fluid otherwise at rest, or the ship is at rest with the current flowing past it. A "Stream Line Surface" is a surface which traverses a number of neighbouring stream lines; and we may conceive a current to be divided by a number of such surfaces into "Elementary Streams." By this device the speed of the current at different points in the same elementary stream may be arrived at, because the velocity will evidently vary from point to point inversely as the area of the transverse section of the stream. The stream line surfaces passing around a body at rest are necessarily surfaces of unequal pressure, and Rankine's investigations dealt exhaustively with the relations of the unequal pressures. Of Rankine's views the late William Froude became a lucid exponent, following them up with beautiful experimental researches, performed mainly, but not entirely, by means of models. His elucidations of these experiments, and his deductions therefrom, were so clear and so comprehensive as to present him to-day in the character of the principal founder of the modern theory of resistance.*

It will already have been seen that, in order to reach this theory, we had to start from very abstract considerations indeed. One of our greatest aids to clear conceptions of it is derived from something anterior even to the stream-line theory as applied to water itself; for our best point of departure is the imaginary movement of a perfect fluid, which, so far as we know, and as we must indeed believe, is itself imaginary. A perfect fluid is a fluid conceived to be absolutely without friction between its parts, and devoid of all viscosity, so that no force is wasted by the

* See his Presidential Address to Section G, British Association, 1875, and the Discourse to the Royal Institution in 1876.

movements of its particles among each other, the *vis viva* of one moving particle being transferred without diminution to another, or to others. Such a fluid would be instantaneously responsive to the pressures exerted by a body wholly and deeply immersed in it, and could offer no resistance save that due to inertia. All the time the motion of such a body is increased in velocity, differences of pressure and accelerations of motion will take place among the particles of fluid. When the disturbing body ceases to be accelerated, and moves on (as we will suppose) with a uniform velocity, a definite set of stream lines and stream surfaces will have been established; the positive and negative pressures upon the body will, by the laws of fluid motion, be precisely balanced; and the whole system of fluid particles and the body embraced by them will advance with a uniform velocity without any resistance whatever. Bring the body from the deep interior to the surface of a perfect fluid, however, and this state of things will no longer exist. The vertical reactions of the fluid from above the body will be lost; an upward movement of the parts of the fluid will take place; this upward movement will result in the formation of waves; gravitation will begin to level these waves as soon as they are created; and energy will consequently be lost. Hence, even were water a perfect fluid, energy would have to be expended upon a floating body to keep it moving at a uniform speed, and this energy would, of course, be the exact equivalent of the energy expended by what would be called the fluid resistance. Here we have, therefore, in the production of waves at the surface, a necessary element of resistance, which clearly will not be got rid of by the substitution of water for a perfect fluid. With this substitution, on the contrary, there will enter a second element of resistance, viz, that due to the friction and viscosity of the water, which oppose every movement of the particles, whether that movement be among the particles themselves, or past the surface of the moving body. And there is a third element of resistance which will enter at the same time, viz., that due to the energy expended upon the production of eddies by abrupt interferences with the general movements of the body and of the water, should such exist. Such is a brief account of the now-received doctrine of the elements of resistance, as I understand it, which has been arrived at by the combined labours of Stokes, Rankine, the Froudes, and others, but is chiefly due to the labours of the late W. Froude.

The wave-making resistance—while operating as a sternward force upon the ship, and capable in that sense of being separated in our minds from the details of wave production—nevertheless actually takes effect upon the water by producing two distinct sets of waves, of which one set travels in the line of the ship's advance, and the other diverges obliquely from it. In an eloquent passage in his Address of 1894 to the Greenock Philosophical Society, Mr. R. E. Froude spoke of the visibility of the effects of each of the now-recognised elements of resistance, viz., friction, eddy-making, and wave-genesis:—

"We may observe the effect of the skin-friction resistance, in the belt of eddying water which clothes the surface of the ship from end to end, getting thicker and thicker as it approaches the stern. We may observe the effect of the eddy-making resistance, in the increase of this eddying mass of water behind the stern. And lastly, the effect of wave-making resistance shows itself plainly to every eye in the wave system which we see spreading away from the ship. We see the effect of what I have termed the 'direct' wave-making resistance in the train of large but long and gently undulating waves following in the wake of the ship, with crest-lines square to the line of motion. And we see the effect of the oblique wave-making resistance, in the feathering crest which diverges from the bow, with its attendant *échelon* waves, stretching away into the distance in an oblique line as far as the eye can reach."

I am greatly tempted to descant upon this branch of the subject at some length; to speak of the quantitative division of the aggregate resistance opposed to a ship into its three elements, due to friction, wave-making, and expenditure upon eddies respectively; and to exhibit to you how many results of experience, that were aforetime anomalous and inexplicable, are made clear and consistent by this new and beautiful theory—one of the most fascinating that could have come to us adventurers into the science of the sea. But it is my unhappy lot to-day to be compelled to drive apace past the newly discovered territories of naval science, giving them but a distant glance at the most, and, in many cases, leaving them wholly unremarked; but I ask you, nevertheless, to believe that these territories are many and fertile, teeming with pleasure and profit for those who, at leisure, explore them. I do not think any better exposition of the modern laws of resistance can be found than that given by Mr. R. E. Froude in his Greenock paper quoted above. Suffice it to add that the labours of a few men, conspicuous among them being officers and members of this Institution, have, since its formation, brought the laws of fluid resistance from the darkness and doubt in which even the most illustrious investigators had left them, and by the combined efforts of genius with those of painstaking experimental research—which some esteem even more highly than genius itself, but which is really the essential friend and collaborateur with genius in the disclosure of natural laws—have laid those laws open to the view, the admiration, and the guidance of our profession.

And what is true of the novel and beautiful theory of resistance is equally true of the whole mathematical theory of Naval Architecture in all its parts. It is a domain in which the mind may expatiate with delight amid the charming complexities and fascinating intricacies of ideal science, knowing that as we become extricated from these intricacies and complexities, and bring into view the simple laws that have occasioned them, our greatest mental qualities will find their highest satisfaction. From the same domain we gather the practical laws which so inform and regulate our professional work as to give increasing security to our sea structures, and seem to justify the hope that in the days to come no structure, however solidly founded upon

the land, need surpass, either in strength, or safety, or beauty, the structures which the naval architect will offer to the use and admiration of the world.

In looking hastily over our Transactions, with a view to this paper, I, who have been pretty closely cognisant of the work from year to year, was nevertheless overwhelmed with the magnitude and merit of the aggregate of what has been accomplished since 1860; and it has been delightful to recognise there the labours wrought by the men of France, Germany, Sweden, Russia, the United States, and some other countries. I have noted, too, with admiration, the almost total absence of jealousies and rivalries among those who, both at home and abroad, have directed trained minds to the advancement of this most attractive branch of our professional work. Debates without number almost we have had, participated in by men whose respective labours have been pursued in places apart, and not infrequently for the improvement and advantage of rival navies; and yet so neutral and so pacific is the scientific work we perform in common, that one may well declare that naval science, like the genius which develops it, is of no person, no class, no country, but is the large and splendid inheritance of all who worthily pursue it.

DISCUSSION.

Mr. F. Elgar, LL.D., F.R.S. (Vice-President): My Lord, we have had the pleasure of listening to a most interesting and instructive description by Sir Edward Reed of the advancement of the theory of naval architecture since the foundation of this Institution. We have also heard, and I am sure that members of the Institution must have heard with considerable pride, of the important part that some of our own members, both British and foreign, have taken in it. I do not propose, at the commencement of the discussion, to attempt to follow Sir Edward Reed through the various stages in the development of the science of naval architecture during the period under consideration. I wish rather to draw attention to another side of the question, a side which, though it has not been referred to by Sir Edward Reed, is, I am sure, as fully appreciated by him as by any of us, because it involves questions in which he has always shown much interest. I refer to the advantage which has been taken of the progress of naval science by practical engineers and shipbuilders, and the extent to which they have acquired the knowledge that has been available, and applied it to the improvement and the more accurate and efficient performance of their work. That is a very important point. It must be obvious that no science of naval architecture would be of much practical value unless those engaged in the design and construction of ships were able to follow its teaching and its results, and to apply its methods in the carrying out of their work. One great distinction between the state of matters in this country with regard to naval science when our Institution was formed and the state which exists now is that, in 1860, the science of naval architecture, advanced as it then was, and it was very advanced in many respects, was not generally understood or appreciated by those engaged in the construction and management of ships. At that time mathematicians and scientific men who understood the theory of naval architecture were not shipbuilders, and ship constructors were not

mathematicians. I was a lad in the Drawing Office at Portsmouth Dockyard in the early and exciting days of the ironclad reconstruction of the Navy. Sir Edward Reed was then Chief Constructor at the Admiralty, and there were many ship designers who were invited, or who obtained permission, to submit independent designs to the Admiralty, showing their ideas of what the warships of the future ought to be. Some of these amateur designers were referred to the chief draughtsman at Portsmouth for assistance in working out their ideas and embodying them in the practical shape of lines and plans of ships; and I remember that, at that time, there was hardly a draughtsman at the Drawing Office at Portsmouth who could safely be trusted to make an accurate calculation of displacement and position of metacentre. While, as to calculating the trim of a ship, it was quite beyond the powers of anybody there. The water-line used to be shown upon the sheer drawing for a novel design, in a position where it was considered it ought to be, or where it would look best, and I well remember the surprise of some of the authors of those designs—amongst whom were distinguished naval officers, who knew exactly the kind of ship they would like to have, but not how to represent their ideas in exact or practical form—and their disgust to find that the plans they submitted with the greatest pride and confidence to the Admiralty used to be returned with very different water-lines upon them from those that we, in our ignorance, had shown in the Portsmouth Drawing Office. Several years after that I was sent out by Sir Edward Reed as an assistant overseer of contract work, after passing through the Royal School of Naval Architecture, and I was instructed to calculate the displacement of a certain ship in dock about which there was some question at the time. The overseer with whom I was placed watched very carefully the processes of measurement and calculation, and after the result was obtained he said it might be all very well, but at the same time I ought to remember there might be a mistake in any calculation of figures, whereas, if he had been ordered to do the job, he could have gone down and looked at the bottom of the ship in dock, and guessed the displacement within a ton, thus avoiding the trouble and risk of error in elaborate calculations. Many other facts might be stated, some of which would appear almost incredible to those who do not know, to illustrate the difference between the science of naval architecture at that time, as it had been developed by and was known to mathematicians, and the knowledge of it that was possessed and utilised by shipbuilders as a class, and by those whose business it was to be responsible for the design and construction of ships. That state of things has now, of course, been greatly improved. There is probably, at the present time, not a first-class shipbuilding yard in this country where any of the difficult problems connected with the construction and behaviour of ships could not be thoroughly and accurately dealt with so far as the existing state of knowledge of the subject will permit. Private shipbuilding yards, as well as the Government Dockyards, now possess highly trained draughtsmen and heads of departments who keep well abreast of the science of the day. This Institution deserves credit, not only because of the work referred to in the paper, that has been done by its members in advancing the pure science of naval architecture and its practical application, but also for what it has done in bringing to the notice of those who are interested in ship construction and the management of shipping what it is to their advantage to know. It has done that in two ways. It has done it by the publication of papers and discussions upon questions that arise from time to time in the various branches of naval science; and it has also done it in very large measure by promoting the institution of schools and educational establishments, the first of which was the Royal School of Naval Architecture and Marine Engineering at South Kensington, the foundation of which was really due to the direct action of this Institution. I think that the work done here, useful as it may have been in advancing the science of naval architecture, has been still greater and of more practical value to the interests of shipping in spreading such knowledge

throughout the shipyards of the country, and in raising the level of the class of men employed in the designing and building of ships. I would only like to say in conclusion, my Lord, how pleased I am, as I am sure every other member present must have been, to listen once again at our meetings to our old friend, Sir Edward Reed, who has done so much for this Institution—at its foundation, and during its already long and prosperous career.

Mr. ARCHIBALD DENNY (Member of Council): My Lord, very much the same idea occurred to me while Sir Edward Reed was reading his paper as Professor Elgar has just voiced. My firm were actually taunted with being scientific. One would think it was rather an occasion for praise, but so far did that taunting go that, occasionally, coming down to practical business, we were denied opportunities of securing work, because we were told we were too scientific to produce it. The work done by my firm has certainly not been mathematical in its purest sense, we took the mathematical theory and actually applied it. I sympathise very much with Sir Edward Reed in reading such a paper as this. It is a fearful undertaking, and it is practically impossible to adhere to one branch of the subject, because the line of demarcation between what is purely mathematical theory and what is practical is so fine that you can scarcely avoid crossing occasionally, and even in Sir Edward Reed's paper he refers to the practical work of making cross curves, and so on, which my brother, William Denny, was engaged in. I think that Sir Edward Reed is to be heartily thanked for compressing into thirty-one closely printed pages almost the whole history of the mathematical theories of shipbuilding.

Professor J. H. BILES (Member of Council): My Lord, I am completely astounded at the ability which Sir Edward Reed has displayed in putting into this small space such a large amount of the whole of the mathematical theory of naval architecture. When I first heard that Sir Edward Reed had undertaken to write a paper on the advances made in the mathematical theory of naval architecture during the existence of this Institution, it seemed to me that he would have to write a volume which would be quite as large as one of our own volumes of Transactions. Now this paper covers so well everything that has been done, in a way in which one would expect it to be treated for such an occasion as this, that it leaves very little for one to say as to what has not been done. The subject of the strength of ships is perhaps the one in which the least amount of mathematical work has been done; though at the present we have in prospect a treatment of the subject by Captain Kriloff, who has given us an opening paper on the subject, which I think will bring the question of the strength of ships into line mathematically with the stability and the resistance. Sir Edward Reed has very ably pointed out that the particular difficulty, or the particular point, which it is desirable to determine in connection with the strength of ships is the factor of safety which we can give in proportioning the amount of material in a ship. Now, the factor of safety, of course, can be inferred in some ways from the practice of bridge builders; and recently I had, for the purpose of a paper in another institution, to read over a great deal of civil engineering research connected with bridge building. I was very much disappointed, in reading through a great deal of work of that kind, to find that I could not get what I wanted; but I was consoled also to find that the subject, as far as civil engineers are concerned, is about in the same state as it is with the naval architects. They have to rely to a large extent upon practical experience guided by mathematical theory. What we can do is, to take a hypothetical case of a ship upon a wave which is supposed to be perfectly at rest, at the moment, and we can find the relative distribution of weight and buoyancy, and from that relative distribution we can determine the shearing forces and the bending moments. Then we have to determine, or consider, how near this hypothetical case is to the

actual cases in which ships are placed. We have first the consideration, that a wave is never at rest. Then the investigation of the structure of the wave comes in, and we find from the investigation of that structure, that the maximum stress which is brought upon a ship is less when the structure of the wave is taken into account than it is in the hypothetical case in which we assume the wave to be perfectly at rest momentarily. Then we have the further consideration, that the ship itself will not be at rest in wave motion. She has a vertical motion, and a pitching motion. With regard to the vertical motions, when taken full account of, we find that the stress is in some cases increased; yet, when the maximum stress comes upon the ship, the effect of the vertical heaving motion of the sea upon a ship is to reduce that maximum stress, from the case which we have considered, of the wave being perfectly at rest. And so on in other cases, we find the hypothetical case, which is not real at all, of a ship being poised momentarily upon the crest of a wave, gives a greater stress than any case that we can find when we put in the fuller considerations which appertain more nearly to actuality. Now, when we take those figures as obtained, and which were first obtained, by Sir Edward Reed in his Royal Society paper a good many years ago now; when we take that stress so obtained and relate that to actual ships, we do get a factor of safety in this way: we find that, when that hypothetical stress exceeds a certain limit in a particular class of ship, the structure of the ship will show signs of distress after hard voyages, and that particular limit finds out for us the factor of safety, when we relate the breaking-down strain to the stress which we determine would come upon it, in the hypothetical case first investigated by Sir Edward Reed. That is a practical factor of safety which can only be ascertained by those who have followed the subject closely for several years, and who also have what may be called the good fortune, but what is sometimes considered the bad fortune, of having built weak ships. It is only by building weak ships that you can find out what the factor of safety is. Nobody likes to build a weak ship, but anybody who has the misfortune to build a weak ship gains in knowledge, and the science of naval architecture is advanced thereby. The strength of ships is a branch of the subject which Sir Edward Reed has made his own very largely, and it is very remarkable to recall that, in the paper he read before the Royal Society, almost the whole of the ground which has been much more developed in recent years was gone over by him in that paper.

M. V. Daymard (Member): My Lord, I desire to thank Sir Edward Reed for his interesting and beautiful memoir, and especially, in the names of the foreign countries here represented, for the liberal justice which he has rendered in his paper to the savants of these countries for their work on the subject of the theory of naval architecture.

Sir William White, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): My Lord Hopetoun, Dr. Elgar and other speakers have expressed most fully an opinion that we all share. In undertaking such a paper as this, Sir Edward Reed has placed the Institution under the greatest obligations. It means no small amount of labour to mass together a statement of this kind and to bring it within narrow limits. When I heard that Sir Edward Reed had been good enough to undertake this duty, I thought that he had undertaken a task which he would afterwards regret. Whether he has regretted it, or not, he has done it, and done it well, and we are, I am sure, deeply indebted to him. It is a great convenience to all of us, whatever may be our acquaintance with these subjects, to have brought before us periodically a sort of summary of what has been done over a considerable period of time. I can quite understand the truth of the feelings which Sir Edward Reed has expressed when he said that, when he came to note down, under the several groups of subjects which he has treated, the advances made in the last thirty-seven years, he was himself surprised. The remark which he has made on page 75, chiefly with regard to stability, is true also in a larger sense. He says,

speaking of stability :—"We must carefully bear in mind that we have had no new elements and no new principles to deal with since 1860." Well, that, as I am sure Sir Edward Reed will agree, is true of other branches of the mathematical theory of naval architecture as well as stability. Speaking of my own experience, I can say now with full confidence that no branch of my education was more profitable than that which embraced the study of the old books on naval architecture published during the last century ; a study to which I devoted a very large amount of time, and in the course of which I discovered how true is the statement that there is nothing new under the sun. Many of the things which we have since worked out in greater detail and in a more formal fashion are clearly indicated by the writers of the last century. Not merely is that true, but in many instances suggestions as to lines of investigation under modern conditions have been found in the study of those old authors. In the years, now far back, when, fresh from the School of Naval Architecture, Sir Edward Reed was good enough to appoint me to the Admiralty, and to give me the opportunity of helping him in his work, I, to some extent, learnt a lesson which I hope I shall never forget. One is apt to think that an idea which comes to him for the first time must be new. That is not always the case. We find buried away in these old books many most remarkable investigations—investigations which are not quantitative, but which are qualitative, and suggestions from which, all my life through, I have reaped the greatest benefit. In regard to the present condition of things, it seems to me there are two matters in which this Institution has been of immense service. The first, to which Dr. Elgar alluded, is its great influence on professional education; and the second, the medium for publication which it has afforded to those who have had something worth saying. Before this Institution existed, there was a danger that much of what was being done was not known—not merely that it was not applied, but that it was not known. Our acquaintance with what was being done in France and other countries was not the same as it is now that we have the pleasure and honour of having so many members of this Institution coming from abroad. There is not the same risk now of things lying dormant and not being made practical use of as there was in former times. To illustrate what I mean, it is a matter of common knowledge that the "law of comparison," which the late Mr. William Froude worked out for himself and applied to model experiments on the resistance of ships, had been previously and completely worked out by M. Reech, but the fact was utterly unknown to Mr. William Froude. That is only one case of many. We really did not know in the same way as we do now what was being done. Another thing on which I think we may congratulate ourselves in this Institution, is the development in various parts of the country of local institutions, which go on and do very valuable work, much of it original. It was thought that the formation of these institutions might be prejudicial to the interests of the parent Institution, but we all know now that that is not so. We all know that much of our good work comes to the Transactions of the Institution from members who are also working for local institutions. Speaking of all the branches of the theory of naval architecture mentioned here, we are glad to know that in the Proceedings of the Institution of Engineers and Shipbuilders in Scotland, and of the North-East Coast Institutions, we can find papers of the greatest merit, which we read with enormous advantage. We may consider that this Institution has been the cause of the formation and extension of many of those local institutions, to the great advantage of the profession. It is astonishing how the history of the theory of naval architecture shows the truth of the saying that any good piece of work is bound to bear fruit in the end. If we think, for example, of the long years that passed before much practical use was made of the investigations of Atwood and Moseley, and how in later days the need has arisen for giving practical effect to their work, and how much good we have got out of it, I do not think we need despair for the future. With regard to many of the papers which are

contributed to our Transactions, and which members are sometimes disposed to look on as not of much practical utility, I think, in the time to come, those who succeed us will refer to some of those papers as having given considerable information on work of naval architecture, ship designing, and propulsion. As regards what still has to be done, we do not forget that we have still with us gentlemen who, while ranking chiefly as mathematicians, are also co-workers with us in what we are doing in the endeavour to advance the theory and practice of naval architecture. We still have with us men whose names will live with those of Atwood, and Moseley, and Woolley. I am glad to see here to-day Professor Cotterill and Professor Greenhill, who represent that class of workers. They may not be so closely in touch with practice as some of us are, but we do not forget what we owe to them, and those before them, in that department of work. Of course our work cannot be purely scientific. I remember well a criticism made on some of my work many years ago by a writer in *The Saturday Review*, who, because I was unfortunate enough to admit that, in the course of five years I had learnt something, and that I did not quite hold the same view which I held five years before, said it was quite obvious that the science of naval architecture was not an exact science. He said it did not compare with astronomy, and that the prediction of the motion of planets appeared more certain than the prediction of the behaviour of a ship. We quite admit all that, and we wish that we could proceed on more certain lines. It is not altogether a comfortable thing to have to go on with these uncertainties, when we have to take into consideration the enormously varied conditions and the partially known risks which we have to face in the construction of ships which must go over all the world, and prove safe and seaworthy. One is tempted to say much on a matter like this which all have so much at heart. I do hope and believe that this work, which has been always international, will continue to be so; that we shall always be ready to learn from, as well as to help one another. It is most suggestive that we are having assistance, not merely from our friends in France, to whom we owe so much in the past, but that new countries, and particularly Russia, are helping in the work of advancement. The other day, in examining at the Naval College, I found students there applying a new method of estimating the displacement of ships—a Russian method, which is the shortest I have seen. It rested, of course, upon a mathematical basis, but in its application was the shortest and simplest, and easiest thing I have ever seen. Again, Professor Biles has noted the fact that, in connection with the behaviour and stresses and strains of ships, Captain Kriloff, of the Russian Naval Academy, is showing us the way in a new direction. Surely this is most encouraging—not merely that these gentlemen should be working in this way, but that the home to which they turn to make known their latest investigations is the Institution of Naval Architects. My Lord, before I sit down I should like, if I may, to express my personal thanks to Sir Edward Reed for the more than kind terms in which he has referred to myself in so many places in this paper, and I should like to add one word of recognition to the memory of my friend Mr. William John. What his loss has been to science no one can tell. I was myself a co-worker with him in all those earlier investigations that have been mentioned. It was impossible for us to say which piece of the work belonged to each, and from the period to which Sir Edward Reed has referred, in 1867 or 1868 down to 1871, we were always together. When we came to write our paper of 1871, to which reference has been made, we quite agreed that in all these matters in relation to the calculation of stability, we were like the Siamese twins, and could not be divided. From the beginning we worked together. Now that he has gone, I should like to say that his loss to the theory and practice of naval architecture is not easy to over-estimate.

[The President having been called away, Sir William White took the chair.]

Mr. J. R. OLDHAM (Visitor from the United States): Mr. Chairman, will you permit me to refer briefly to one small paragraph of this very exhaustive paper by Sir Edward Reed. On page 71 he refers to the practice of docking vessels without bilge blocks. Now, I have had some twenty years' experience in examining ocean vessels, and have found, in many cases, that after only a few years' work—particularly in the North Atlantic trade—the bilge and bottom butts are so severely strained and opened as to frequently require new plates or outside straps. This is not so on the lakes; and, in case you should imagine that our iron steamers are all new, I may say that we have iron steamers twenty or thirty years old; and, indeed, we have one fifty-four years of age—the iron steamer *Michigan* having been built at Erie in the year 1844, and she is, I believe, the oldest iron steamer in active service in the world. Now, we have steel steamers of 8,000 tons, and more, displacement, and 50 ft. beam, but we never find the bottom butts so severely strained as I have seen them in this country, and I think the different practice in docking may account for this immunity from butt straining. We dock such steamers as I refer to in about two hours. When they are dry and ready for survey, during the time the water is being pumped out of the dock, the bilge blocks are being drawn under the bottom, so that the bilges are fully supported before the water is pumped out. I would ask Sir Edward Reed, if not too much trouble, to give his opinion as to whether it is fair treatment of a steamer of 60 ft. beam, or over, to leave the bilges quite unsupported during the process of emptying the dock? .

Mr. W. T. COURTIER-DUTTON (Member): Mr. Chairman and Gentlemen, I do not venture to offer anything in the way of detailed criticism of the able paper which Sir Edward Reed has given us, but there is a point which occurs to me in connection with the remarks which you, sir, have made, and to which Professor Biles and other speakers also alluded, having reference to the difficulties in connection with the assessing of the strains which are set up in vessels of the Mercantile Marine. We all know that naval architecture is not an exact science; that is to say, that the assumptions which are made in our calculations of the moment of inertia are merely theoretical, and that the actual strains which a vessel has to bear when she is at her work are very difficult to define. We know that those strains are constantly varying. We have the longitudinal strains; we have the vertical strains; and we have what are known as the racking strains, which are probably a combination of the two. In fact, the vessel has a tendency to assume a form which may be best described, I think, by an article of very common domestic use—that is, a corkscrew. I should like to remark, also, that these difficulties are very much increased by the unfair treatment to which owners are subjecting vessels. There is a growing practice of sending vessels to sea—vessels of full, modern type, and with somewhat insufficient power—in ballast. The Register Societies have occasionally had brought under their notice cases of this kind, where vessels are practically rendered as unfit as possible for meeting these severe strains; vessels sent across the Atlantic, for instance, in winter-time, when it is a difficult thing for them to fulfil their work satisfactorily. With the large passenger vessels that are sent to sea under the best conditions of trim, and under practically constant conditions of loading, it is a different matter; but with vessels of a smaller type, sent away to their work in ballast, and meeting with bad weather, it becomes a question as to whether some special provision should not be made to meet this growing practice. With regard to the remarks made by the last speaker in connection with the strength of the bottoms of the American lake steamers, and their peculiar adaptability to docking, I understand that these vessels, in order to cope with the frequency of grounding, have extra depth in the double bottom, extra depth of girder, which renders a comparison with the vessels built in our country somewhat unfair. I am not sure, but think I am right in that.

Mr. J. R. OLDHAM: As regards Mr. Dutton's remark that our double bottoms are deeper, I may say that our floors are shallower, and so I think that will not explain the discrepancy between lake and ocean vessels. I am inclined to the opinion that the practice in dry docking has something to do with this.

Sir EDWARD REED, K.C.B., F.R.S. (Vice-President): Sir William White, Ladies and Gentlemen, I have nothing to say at all by way of reply. I have only to express my thanks to those gentlemen who have so kindly referred to my paper. I should like to explain, however, as the undertaking of this paper has been frequently mentioned, it might be supposed that I did it quite voluntarily. The truth is that a year ago, when this Congress was thought about, I suggested to a few of our members, including our most successful and respected Secretary, that for my part I do not believe in pleasure functions unless they are associated with a continuance of our work as an Institution, and that I should be very sorry to see the real work of the Institution in any way neglected in the pursuit of pleasure; and I said also at the annual meeting that I thought there should be three papers, as it was to be of a commemorative description, one summarising the mathematical progress during the period of the Institution's existence, another summarising the shipbuilding progress, and another summarising the engineering progress. I can assure you when I suggested those things I never imagined that the labour of either of those divisions would be put upon me. I am glad to know that two out of the three have been carried out. We had an admirable paper from Sir John Durston and Mr. Milton yesterday summarising the progress of marine engineering. I was charged with the responsibility by the officers of the Institution of writing this paper, and I must say I thought it rather unfair to a man who must necessarily be a little rusty in his mathematics now. I think, sir, the speakers have done full justice to the magnitude of the work of undertaking such a paper. It is not a very satisfactory task, because you have to do an immense amount of work which only takes its result in a sentence or two in the paper, and, as you, Sir William, suggested, you have not only to go over the ground and bring out the information, but you have then to cut it down to a very narrow limit. I can assure you it would have been much easier to have written this paper at ten times its present length. At the same time, Sir William, I am very glad to have been so far successful as to elicit no very serious criticism upon the summary I have attempted, although I do not infer from that, that you and other gentlemen present could not have criticised it if you had wished; because I think your idea has been that, if the general work of attempting to sum up the progress has been honestly attempted and fairly made in the paper, it might well be allowed to pass by without minute criticism. You, sir, spoke of my frequent allusions to yourself in the paper. I am bound to say that I have had a single mind in writing this paper, and that was to do whatever the progress of the subject rendered necessary in the way of recognising individuals, and if I have made a frequent use of your name, Sir William, it will be easily accounted for by everybody as the natural consequence of your own activity in the work. I am much obliged to you all for the manner in which this paper has been received.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, I am sure you will wish me, in your name, to convey our sincerest thanks to Sir Edward Reed for his labour in preparing this paper, and our congratulations on its successful accomplishment.

DANISH STEAM RAILWAY FERRIES AND ICE-BREAKING STEAMERS.

By Captain I. C. Tuxen, Director of Naval Construction and Engineering, Royal Danish Navy, Member.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President, in the Chair.]

Denmark, besides the Peninsula of Jutland, consists of a great number of islands, separated from one another by sounds or belts.

Most of these waters are shallow, at least near the harbours; only the larger of them may at times be rough. During the winter they are often filled with ice for one or more months; in some cases the ice covers the whole surface, but in other cases it is drifting.

Across these waters there is a considerable traffic, and great efforts have been made by the State and private firms to continue this traffic uninterruptedly during the whole year. The State railways have provided a floating *matériel*, consisting of steam railway ferries and ice-breaking steamers specially adapted for the purpose.

I venture to think that the special features of these vessels contain several points of sufficient interest to the members of this Institution to excuse my bringing the matter forward on this occasion.

I.—Steam Railway Ferries.

Formerly the traffic was carried across the water in ordinary paddle steamers, but the trouble of transhipment of the goods at each crossing led to the construction of steam ferries.

The first steam railway ferry was a paddle steamer, built in 1872 in Newcastle, capable of carrying five goods wagons on a single line of rails. The next ferry (similar to the first) was built in 1877. Four larger ferries were built in 1883, and the development has continued, so that the State railways now possess fifteen steam ferries, besides one building.

Table I. annexed gives the principal data of these ferries.

Ten of the ferries have a single line of rails, but the five largest have double lines. Twelve of the ferries have paddle-wheels, and only three have screw propellers. Two of the latter, fitted with twin screws, are running across a narrow channel, and can work better through ice than paddle-steamers could do. The single-screw ferry is really an ice-breaking ferry, and will be described further on.

Detailed description of the ferries is unnecessary, as they are much like ordinary passenger steamers and ferries. Some special features of the class may be mentioned, and a short description of one of the largest ferries will suffice.

The first ferries were constructed to take goods wagons only, and thus to avoid the transhipments of goods. This principle has been followed throughout the development. Passenger carriages, as a rule, are not taken on board. In some cases a few through carriages are taken, the bulk of the passengers leaving their carriages at the ferries. Comfortable saloons for passenger accommodation are fitted underneath the deck in all the ferries, being well heated and ventilated, and in the later ferries lighted by electricity.

All the ferries have heavy timber fenders round the outside from end to end, at the height of the deck. The shape of this fender at the ship's ends is exactly the same for all the ferries, so that they may all fit in the different ferry harbours belonging to the seven crossings at which railway ferries are used.

The piers of the ferry harbours are constructed of timber and shaped to the form of the ferry; this goes end on into the berth and is stopped by buffers. A hinged bridge is lowered to the end of the ferry, which is arranged to receive the bridge, over which the wagons roll on board or ashore. As there are no great variations in the water-level, such as occur in tidal harbours, the difficulties are much reduced.

The lines of rails pass through the whole length of the deck of the ferries, and the wagons can be shipped or unshipped at either end, these being alike. The rails are placed directly on the plating of the deck and bolted to it. Underneath the deck-beams heavy longitudinal girders are built, one for each rail in the small ferries, and one for each line of rails in the large ferries, to take the weight of the railway wagons. The girders are again supported by a number of pillars.

The paddle ferries have a rudder at each end, and steam practically as well astern as ahead; they vibrate, however, rather more going astern.

The arrangements and installations are very similar in all the ferries, and a general idea of them may be had from the drawing of the largest ferry, the *Kjòbenhavn*, built in 1895, which needs no further explanation. (Plates XIV. and XV.)

The engines of this vessel are compound, with the cylinders placed diagonally. There are two high-pressure cylinders, 34 in. in diameter, and two low-pressure cylinders, 62 in. in diameter; the stroke is 54 in. There are four cylindrical boilers, with a steam pressure of 85 lbs. per square inch.

The ordinary full-power speed of this vessel at 9 ft. draught is 12·9 knots ahead or astern, with 1,400 I.H.P. On the measured mile the vessel has, at the same draught, made 14·4 knots, with 2,155 I.H.P.

II.—Ice-breaking Steamers.

Formerly, when the sounds and belts were filled with ice, the traffic was carried across in open boats with huge bilge keels, on which the boats could slide on the ice. This was, however, a primitive way, and it was consequently found necessary to build ice-breaking steamers.

Table II. gives particulars of the ice-breaking steamers now existing. The five first named are used for carrying the traffic across the sounds and belts when the steam ferries cannot work on account of ice. The *Bryderen* belongs to a private company, the four others belong to the State railways. The fifth, the *Sleipner*, is used for keeping open the free port of Copenhagen during icy winters, and to assist merchant vessels in getting through the Sound to or from the free port.

The first ice-breaker, the *Staerkodder*, did not quite answer the purpose. The reason for this was that she was intended to be a good passenger and cargo steamer at the same time as an ice-breaker, and that she was given a very small draught on account of the shallowness of the water where she has to work. As seen from Table II., the length is great relatively to the breadth and draught, which has proved to be a drawback. Further, the vessel has twin-screws, and these are too close to the water-line, as the tanks aft are not large enough to put the vessel well down by the stern. Consequently the propellers are much exposed, and the blades often break off. At first the propeller blades were of gun-metal, but now they are of cast steel, which stands better against the ice. The engine power also proved to be insufficient for the work, the total indicated horse-power being only 800.

Experience gained with the *Staerkodder* was profited by in the construction of the next ice-breakers, and these have all proved to be very successful, both for working through water filled with drifting ice and through a thick layer of ice covering the water.

Comparing the *Staerkodder* with some of the later ice-breakers (for instance, the *Mjölner* and *Thor*) it will be seen from Table II. what alterations have been made to secure better ice-breaking qualities. These vessels are made 15 ft. shorter, 5 ft.

broader, and have 2 ft. 3 in. more draught. The draught can be much increased, as the water tanks aft are considerably larger and the longitudinal stability smaller than in the *Staerkodder*. The later vessels have a single screw propeller, and this can be brought well down underneath the water, and is thus better protected than the twin-screws of the *Staerkodder*. The engine power has been much increased, being 1,350 I.H.P. on the full-power trial of two hours' duration.

A short description of the largest and newest ice-breaker, the *Sleipner*, of which drawings are annexed, will serve for all the class. (Plates XI., XII., and XIII.)

The principal dimensions of the *Sleipner* are given in Table II.

The hull is very strongly built, to be able to resist the enormous pressure of the ice. The frames are placed much closer together than usual, the frame-space being 15 in. in the fore body and 18 in. in the after body, while Lloyd's require 23 in. for a vessel of this size. The plating is further stiffened by six transverse watertight bulkheads, and five web-frames in engine and boiler rooms.

The outside plating is unusually thick, being $\frac{7}{8}$ in. below the main deck in the fore body and $\frac{13}{16}$ to $\frac{11}{16}$ in. amidship and aft. This thickness is, on the average, 50 per cent. greater than required by Lloyd's rules for a vessel of that size. The plating is worked flush-jointed, with internal butt and edge straps, to form a smooth surface, on which the ice can take no hold.

The longitudinal ties inside the vessel (side keelsons and deck stringer plates) are also well strengthened, and carried through the whole length of the vessel.

The shape of the bow is specially designed for breaking the ice. The "water-lines" are very full, and the "bow-lines" fine, the forefoot being cut away. When the vessel is trimmed by the stern for ice-breaking, and steams ahead, the bow presses the ice downwards and breaks it. The shape of the bow is like a "spoon"; only that the stem projects somewhat further out than usual in steamers, forming an edge, which facilitates steering in open water.

Two water-ballast tanks are built in each end of the vessel for trimming. By filling the two tanks aft, the draught aft is increased 4 ft. 2 in., whereby the propeller comes well below the water surface. The two forward tanks when filled increase the draught forward 4 ft. 11 in. The tanks are filled and emptied by a large centrifugal pump placed in the engine-room. It takes about six minutes to fill or empty each tank. The air pipes of the tanks have the same sectional area as the water-supply pipes, to avoid any undue pressure on the walls and top of the tanks if the pump is not stopped at the moment they are filled.

The machinery consists of a vertical compound engine, with two cylinders of 40 in. and 70 in. diameter, and 36 in. stroke. To resist the strain brought on the machinery through shocks of the propeller against the ice, all parts are made extra strong: the shaft, for instance, is 20 per cent. stronger than required by Lloyd's rules.

A compound engine was chosen in preference to triple-expansion. This was done for the sake of the boilers. When the vessel has to break heavy ice by ramming, going forwards and backwards alternately at full speed, the steam pressure is very fluctuating, which would be trying to the boilers if the high pressure required by triple-expansion engines were used. On the other hand, the saving of fuel gained by triple-expansion would not be great for the kind of service required by this ice-breaker. To get a low consumption the boilers are designed with large heating surface to a steam pressure of 100 lbs. per square inch. For the same reason the engine is fitted with an expansion slide.

The screw propeller is made very heavy, of cast steel, with loose blades that can be shifted while afloat. This is done by the following device patented by Mr. Olsen of Elsinore, and indicated in Plate XIII. A well is built in the vessel right above the propeller, the top and sides can be shut air-tight. Access to the well is through a hatch in the upper deck. Through a large hole in the bottom of the well works a vertical tube, which can slide down to the boss round a propeller blade. Air is pumped into the well, which forms thus a diving bell. Spare propeller blades are stowed in the well. When the tube is hauled up, the lower opening in the vessel for the well is closed by a steel plate.

When the vessel is working in ice it is difficult to get the necessary cooling water for the surface condenser. There are three sea valves for the entrance of this water; namely, two in the engine-room, placed somewhat apart and at different heights, and a third in the foremost ballast tank aft, which can be opened and shut from the engine-room. When there is much ice, the valves are apt to get choked. The cooling water is then taken from the ballast tank and returned to this again. Now and then the water in the tank is renewed from the sea. If necessary the vessel is stopped to free the sea valve of ice, as it is not so apt to choke then as when the vessel is moving. In this way it is possible to keep a good vacuum.

The vessel can carry 250 tons of coal. Loaded with 40 tons of coal and all four ballast tanks filled, the vessel easily maintains a speed of 12¾ knots, which requires 2,000 I.H.P. The engines are able to develop 2,600 I.H.P., which give a speed of 13·4 knots when loaded as mentioned.

Probably no more ordinary ice-breaking steamers will be built for the Danish State railways, as ice-breaking railway ferries will be preferred. The first of these, the *Jylland*, particulars of which are given in Table I., has been built and proved successful. Her

main features resemble those of the ordinary ice-breakers, but the length is relatively greater, to get room for railway wagons. The ice-breaking qualities have proved to be satisfactory, but the manœuvring qualities do not quite come up to those of the ordinary ice-breakers, on account of the greater length. The advantage of being able to carry the railway wagons is, however, so great that the ice-breaking ferry is preferred.

Experience gained with existing ice-breakers shows that they work in ice as well going astern as ahead, and for this reason it is under consideration to build the next ice-breaking ferry with a propeller at each end, like those in America. The advantage gained is lesser draught; the only fear is that, the vessels being small compared to the American, each of the two engines may be rather small for the work.

I hope to have given in this paper some impression of what has been done in Denmark to carry the railway traffic across the sounds and belts. Considered in relation to the size of the country and the population, the undertaking is doubtless greater than any similar work done in any other country.

TABLE I.

Name.	Built.	Builder.	No. of Lines of Rails.	Paddle or Screw Steamer.	Length between Perpendiculars.	Breadth, Moulded.	Depth, Moulded.	Full Power Trial.						I.H.P.	Speed.	No. of Waggons to be Carried.	Cost of Building
								Draught Forward.		Draught Aft.		Displacement.					
					Ft. In.	Ft. In.	Ft. In.	Ft.	In.	Ft.	In.	Tons.			Knots.		£
Lille Belt ..	1872	Wigham Richardson & Co., Newcastle	Single	Paddle	140 0	26 0	..	7	3	7	3	..		340	8·0	5	9,900
Fredericia ..	1877	Schichau, Elbing..	„	„	140 0	26 0	..	7	3	7	3	..		360	8·0	5	9,400
Korsór ..	1883	Kockum, Malmó	Double	„	250 0	34 0	16 0	8	10	9	0	1,220		1,700	13·0	16	31,300
Nyborg ..	1883	„ „	„	„	250 0	34 0	16 0	8	10	9	0	1,220		1,700	13·0	16	31,300
Hjalmar ..	1883	Schichau, Elbing..	Single	„	166 0	26 0	12 0	7	0	7	0	440		600	10·0	6	12,600
Ingeborg ..	1883	„ „	„	„	166 0	26 0	12 0	7	0	7	0	440		600	10·0	6	12,600
Valdemar ..	1886	Burmeister & Wain, Copenhagen ..	„	Twin screw	140 0	31 6	13 0	7	0	8	0	540		700	11·0	5	13,800
Sjalland ..	1887	„ „ „ ..	Double	Paddle	274 0	34 0	16 0	9	2	9	2	1,445		2,055	13·4	16	39,400
Dagmar ..	1889	„ „ „ ..	Single	„	166 0	26 0	12 6	7	9	7	9	495		470	10·2	6	14,700
Marie	1890	„ „ „ ..	„	Twin screw	140 0	31 6	13 0	7	0	8	0	540		700	11·0	5	15,200
Krprs.-Louise	1891	Elsinore Shipbuilding Company ..	„	Paddle	166 0	26 0	12 6	7	11	7	11	570		710	11·0	6	17,100
Alexandra ..	1892	Burmeister & Wain, Copenhagen ...	„	„	177 0	26 0	12 9	7	10	7	11	582		634	10·8	6	17,300
Thyra	1892	„ „ „ ..	„	„	177 0	26 0	12 9	7	10	7	11	582		600	10·2	6	16,600
Jylland ..	1894	„ „ „ ..	Double	Single screw	171 0	36 0	19 2	10	9	12	2	1,015		1,210	12·2	10	27,100
Kjóbenhavn	1895	„ „ „ ..	„	Paddle	274 0	34 0	16 6	8	10	9	1	1,392		2,155	14·4	18	41,500

TABLE II.

Name.	Built.	Builder.	Single or Twin Screw.	Length between Perpendiculars.	Breadth at Water Line.	Depth Moulded.	Draught Forward, Ordinary Trim.	Draught Aft, Ordinary Trim.	Displacement.	Draught Aft, with Tanks Aft Filled.	I.H.P. on 4 Hours' Full Power Trials.	Speed.	Cost of Building.
				Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Tons.	Ft. In.		Knots.	£
Starkodder..	1883	Burmeister & Wain, Copenhagen ..	Twin	150 0	27 6	14 0	—	10 6	625	11 2	800	—	24,500
Bryderen ..	1884	Kockum, Malmó..	Single	131 0	31 8	15 2	11 7	13 0	—	—	—	..	22,900
Mjólner ..	1890	Elsinore Shipbuilding Company ..	„	135 0	32 8	15 7	10 9	12 9	728	16 0	1,350	12·2	23,200
Thor	1890	Motala & Lindholm, Sweden	„	135 0	32 8	15 7	10 9	12 9	728	16 0	1,350	12·2	22,550
Tyr	1894	Elsinore Shipbuilding Company ..	„	136 0	33 11	15 7	10 9	12 9	735	16 0	1,350	12·2	22,550
Slejpner ..	1896	Burmeister & Wain, Copenhagen ..	„	161 5	39 0	18 6	12 9	17 9	1,450	22 3	2,600	12·75	33,300

DISCUSSION.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Ladies and Gentlemen, this is a paper of a descriptive nature, a paper of information which perhaps does not admit of lengthy discussion, but we may be sure that the vessels described here have come to be what they are because they are found to be best fitted and most efficient for the work they have to do. The information given will be of great value in our Transactions, and we are much obliged to Captain Tuxen for giving us this paper. I would suggest that the discussion need not be restricted absolutely to the Danish type of railway, ferry, and ice-breaking steamer, but that it will be quite proper for any gentlemen present who have had experience in other classes of ship to add for our information any points they may desire. There are some gentlemen here who know much about ice-breaking vessels, and I will ask Mr. Swan to open the discussion.

Mr. H. F. SWAN (Member): Mr. Chairman, the accidents of business have so happened that, in the last few years, I have had to give great attention to building precisely the vessels which Captain Tuxen has referred to in his paper, or rather, vessels to fulfil a service of the same description, because the vessels which I am going to speak of do not resemble in every particular those that Captain Tuxen has referred to. About three years ago a Russian railway company, whose railways terminated at either side of the Volga, found it necessary to continue the service, and the alternative lay between building a bridge costing about a million sterling, or of adopting some kind of ferry or ice-breaking vessel which would allow an uninterrupted service right through the winter. The conditions to be fulfilled were extremely difficult. To begin with, any vessel for this service, which was to be sent out complete to its destination, had to pass through the canal locks, which were only 150 ft. long and 28 ft. wide, and with a draught of water of little more than 5 ft. Again, the difference of water level in the Volga between the highest and the lowest is about 45 ft., so that it became an extremely difficult problem to meet all these conditions. In going into it we came to the conclusion that it would be necessary to employ two kinds of vessels. With a restricted draught it would not be possible to make a ferry steamer sufficiently strong and powerful to be also an ice-breaker. We therefore proposed an ice-breaker proper and also a ferry-boat to carry the complete train. The ice-breaker was 1,400 H.P., and was to be capable of breaking ice up to between 2 ft. and 3 ft. thick. This she has successfully accomplished during the last two winters. The ferry steamer had to carry twenty-four railway carriages, and special means had to be adopted for getting these carriages on and off at the varying heights of the river. Forty-five feet we found was rather too difficult a step to negotiate at one swoop. We therefore proposed that the landings on the sides of the river should be divided into two heights, and that the scope of the hydraulic appliances for lifting the carriages to the required height should be only one-half of the total. This also has been proved entirely successful in actual operation. There are four lines of rails on the ferry, and each of the pairs of rails converges into a separate hydraulic lift at the bow of the ship, and it has been found in practice that the whole twenty-four wagons can be taken on, or put off from, the vessel in half an hour. I referred to the difficulty of getting such vessels to their destination. That, I may say, we have accomplished by dividing the ice-breaker longitudinally into two parts, and the ferry-boat, which was herself nearly twice the width of the canal, into four parts longitudinally and transversely. Both vessels steamed to St. Petersburg, were dismantled, passed the canal locks, were rejoined and proceeded to their destination, and are at work at this moment. As regards the question of single or twin screws, I am very strongly of opinion that all the advantages which accrue in having twin screws in

an ordinary ship are doubled in the case of an ice-breaker. There is not the same risk of damage to the propellers when you can have the propellers smaller in themselves, and therefore the blades relatively stronger. In America it was found that an ordinary ice-breaker, coming astern from a landing, destroyed the ice almost better than when going ahead. That suggested to the Americans to place a propeller in the bow also. It appears to have a disrupting effect on the ice, which renders the ultimate breaking of it much easier. A large combined ferry and ice-breaker which we built last year for Lake Baikal, has twin screws aft and a single screw forward. We are just commencing the construction of a powerful ice-breaker for service in the Gulf of Finland, which will have a single screw aft and a single screw forward. Personally, I should have preferred seeing twin screws aft. This question of ice-breaking is one which I believe will be greatly developed in the future, especially in Russia, which has such an extent of ice-bound coast. I recently had occasion to see a paper which was read by Admiral Makaroff of the Russian Navy, who has given great attention to the subject, and in which he puts boldly forward the idea that the Gulf of Finland, for instance, or any other ice-bound seas, should be navigated by very powerful ice-steamers, and communication thereby kept up all the year round. I am sure the Institution is very much indebted to Captain Tuxen for having brought forward this paper, possessing as it does many points of very great interest.

Captain K. Neilsen, R.D.N. (Member): Mr. Chairman, you will excuse my not being able to speak your language fluently, but I will do my best to tell you something about an ice-breaker which my firm—Burmeister & Wain, of Copenhagen—built for the Russian Navy some months ago. It was a ship made for the port of Vladivostock, and we did our best to make the ship as strong as possible according to orders from the Russian Navy. The engine was not built on the principle of triple expansion. For ice-breaking service you ought to have an engine as simple as possible and as strong as possible, and not go in for those special inventions which relate to coal consumption, and so on; therefore the engine ordered by the Russian authorities was of the ordinary compound type, but very strongly built, and the horse-power went up to 3,500. The ship was very strong, with 1 in. plates round the water-line. We tried the ship in the waters of the Gulf of Finland, and we met with very heavy ice. In these waters during Spring the ice is moving, and it often packs up to great thickness—in some shallow places even down to the bottom—one piece of ice on the other, and that causes very great difficulty to ice-breakers. My friend, Captain Tuxen, told us something about a propeller in front. It is a great question, now discussed in the countries round the Baltic, which ice-breaker is the best, the one with a propeller in the bow as well as aft, or the one with a propeller only aft—as was the case with the Russian ice-breaker we were trying. In breaking the ice on our way to Baltic Port we, for some distance, had up to 12 ft. or 14 ft. of ice packed, but we succeeded in forcing that barrier by hammering through with the bow. The ship advanced with 3,000 H.P. only about half its length for each run, but after about half an hour's work we succeeded in breaking the barrier. I am not sure that such a work would have been possible with a boat having a propeller in front; at all events, it requires a great deal of experience before you can say. There is one thing you must note. There is a great difference between dealing with ordinary firm ice, even of a thickness of two or three feet, and pack-ice. In the first case the front propeller, no doubt, will do its work well. In Denmark we sometimes act in a similar way with our single-screw boats in going astern through the ice, but in all these cases the propeller blades work below the ice. It is quite another thing to force the ship through heavy pack-ice, and, according to my experience, with Danish ice-breakers as well as with the big Russian one, I feel it very doubtful if a front propeller would have been able to stand the work which the Russian ice-breaker did in forcing the barrier

before Baltic Port. I am glad the ice-breaker question has arisen in this Institution, because, as my friend told us, it is a very grave question with regard to navigation in northern countries.

Mr. ANDREW BROWN (Visitor): Mr. Chairman and Gentlemen, I can only say that my firm (Messrs. Wm. Simons & Co., Limited, of Renfrew) built the ferry steamer *Finnieston* to take passenger and vehicular traffic across the Clyde at Glasgow Harbour. It has been working now for seven years, and has done its work well. The *Finnieston* is a special type of vessel, having a moveable deck or platform that is lifted and lowered, so that vehicular and passenger traffic is carried and landed on to the quays at any height of the tide. The range or lift of the moveable platform is 15 ft. There are two sets of propelling engines and two screw propellers at each end of the boat. We cannot call them either stern or bow screws, as the boat runs either way. The advantage of having two propellers at both ends is that the boat, in crossing, can be manœuvred and turned round quickly to clear the large number of vessels passing up and down the harbour. At each end of the boat there is a rudder, but they are not used. The dimensions of the *Finnieston* are:—Length, 80 ft.; breadth, 43 ft.; depth, 12 ft.; loaded draught, 9 ft. The hull is built of mild steel, subdivided with thirteen watertight bulkheads; the elevating deck platform is 78 ft. long, extreme breadth, 32 ft.; the central part is 19 ft. in width and laid out for vehicles, while 6 ft. space on each side is reserved and seated for passengers. An independent engine drives the gear for raising and lowering the platform. It consists of six mild steel screws supported by six steel box columns; the six screws are turned by worm gear, and move the platform up or down: the screw nuts and collars are of manganese bronze. The propelling engines are two independent sets of three-cylinder, surface-condensing engines with two mild steel boilers; the propelling shafting runs fore and aft the full length of the vessel. The propelling and elevating engines and boiler are placed in a compartment in the centre of the boat, and there are fore and aft bulkheads at the sides with cross division, which, in case of collision, render the boat nearly unsinkable. The *Finnieston* carries 300 passengers and ten loaded carts and horses, or if passengers only are carried the number she can take is 700.

Mr. J. BREDSDORFF (Member): Mr. Chairman, I scarcely know, so unprepared as I am, if I shall be able to explain exactly what we have tried to do in the matter of ice-breaking, but I will do it as well as I can. In Flensburg we are situated on a deep bay, where in the Winter we have ice about one foot to one foot and a half thick. This ice is usually lying in a plane, and is seldom piled up into mountains, as there is no current in the bay. We have built a round pontoon about 40 feet long and 35 feet broad, suitable for a cargo steamer about this breadth. (Plate XVI.) The pontoon is 4 ft. deep, and has on the after side an opening like the split in a flag, just fitting the ship's bow. It is fastened by means of chains leading to the ship's deck, and is also screwed on to the stem of the ship, so that it cannot slide up or down. When the ship goes ahead the pontoon moves on top of the ice, and the ship presses the ice down and breaks it to bits. In this way the pontoon makes a channel in the ice, wherein the ship can force its way without stopping. We have built two such ice-breakers on this system, one small and one large, and both of them have worked first-rate. With the large one a Danish steamer made her way from Pillau to Königsburg and back in ice 15 in. thick without stopping, and was highly spoken of by the captain of this vessel. Of course such an ice-breaker can be built at a very low price compared with the ice-breakers which Captain Tuxen has described; the cost amounts to about £2,000. A drawback to this system is that the pontoons have no propelling power, and must be towed back when the ship has reached clear water. The inventor of this arrangement is Mr. Weedermann, of Flensburg, who has worked practically several years with ice-breakers. This idea, which I have described, seems to be very rational. The two pontoons which we have built are

fitted with water ballast, but I should think it is not necessary, as it is with the weight of the ship that the breaking is done, and this power is so great that no ice can resist it.

Captain I. C. TUXEN, R.D.N. (Member): Mr. Chairman and Gentlemen, I have not much to say in reply, except to thank you for the kind way in which my paper has been accepted, and to thank the gentlemen who have taken part in the discussion. It was at the request of Sir William White that I got up this paper for the Institution, and I had no greater desire than to meet the request of my old tutor. If I have at the same time given a paper which is of interest to the Institution, I am fully satisfied.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Gentlemen, it is not any formal vote of thanks which I propose to Captain Tuxen for giving us this paper. Our great desire at this Congress was to have papers from as many sources as we could, and Captain Tuxen has taken some trouble in putting these facts together, which cannot fail to be of interest, because published accounts of this class of vessel are not very numerous, and experience in Denmark is rather special. As Captain Tuxen has said in the last sentence of his paper, we must not forget that, in relation to the size of the country and the population, this undertaking of ice-breaking and railway ferries is really larger than we can see in any other part of the world. I thank the author on your behalf.

ON GRAPHIC AID IN APPROXIMATING HULL WEIGHTS.

By J. Johnson, Esq., Member.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President, in the Chair.]

It is essential for every naval architect to arrange his data, whether derived from actual results or calculations, in such a convenient form, that weight estimates of a ship's hull and its outfit can be prepared quickly and with reasonable accuracy, when fixing proportions and dimensions of ships.

Up to the present day we seem to possess a somewhat meagre literature on this subject.

The most common system in vogue of approximating to a ship's weight seems to be, by using the ratio between the weight and a cubic number, usually derived by multiplying together the three principal dimensions of the vessel and comparing this with the same ratio in a known vessel of similar type.

This method, however, lacks the scientific basis, without which any rule or formula is unreliable, and may lead to confusion and error, where there is any considerable difference in size and fineness between the ships for which the comparison is made.

The difficulty lies chiefly in finding a quantity which not only includes the principal dimensions of a vessel, but also its degree of fineness, and, above all, bears a near relation to the qualities upon which depend the determination of suitable scantlings.

After trying various methods and laying down the data graphically, I came ultimately to the conclusion that the longitudinal number, used by Lloyd's Register of Shipping, and modified in some cases, is a most handy and suitable quantitative expression for comparison of weights, and have ventured to lay the system, which I have been in the habit of using for some years, before this Institution.

By plotting down known weights of iron or steel used in the construction of the hulls of a large number of vessels, in relation to Lloyd's longitudinal number, drawing curves through the mean values of each type, and analysing these curves to find their

equations, the finished weight of iron or steel may be found to follow a general law which can be algebraically expressed by the formula—

$$W = c\,N^{\chi}$$

For convenience of calculation this formula may also be written—

$$W = k\left(\frac{N}{100}\right)^{\chi}$$

Where W = Finished weight in tons of iron or steel, used in the construction of the hull.

N = Lloyd's longitudinal number modified as follows:—In three-decked vessels the girths and depths are measured to the upper deck, without deducting 7 ft. In spar and awning-deck vessels the girths and depths are measured to the spar or awning decks respectively. In one, two, and well-decked vessels the girths and depths are taken to the main deck in the usual way.

c and k are co-efficients, varying with different types, and

χ is an exponent, also varying with different types.

The following table gives mean values of c, k, and χ for vessels built to the highest class at Lloyd's or Veritas :—

Type of Vessel.	C	K	χ
Three-deck	0·00078	0·492	1·40
Spar-deck	0·00115	0·576	1·35
Awning-deck	0·00167	0·665	1·30
One-deck, two-deck, and well-deck	0·00215	0·856	1·30
Sailing vessels	0·00065	0·410	1·40

By means of diagrams, such as those shown on Plate XVII., the weight for a given vessel is more readily found than with the formula. Supposing, for instance, the weight of steel is 590 tons in a two-deck steamer with large deck erections, whose longitudinal number is 14,600, then the weight of material in a similar ship, having a longitudinal number of 12,250, is easily proportioned on the diagram to be about 470 tons. (See Fig. 1, Plate XVII.) In this case $k = 0{\cdot}907$. In a three-deck steamer whose modified longitudinal number (girth and depth taken to upper deck, without 7 ft. deduction) is 30,400, the weight of material was found to be 1,390 tons; then for another three-deck steamer, with similar specification, and whose longitudinal number, taken in the same way, is 34,800, the weight may be approximated to be 1,678 tons. (See Fig. 2, Plate XVII.) In this case $k = 0{\cdot}464$.

Of course, any difference in extra scantlings, extension of double bottoms, number of bulkheads, length of deck erections, &c., between the two vessels must be estimated separately.

The weights of almost all the different parts of a ship's hull can also be displayed by means of curves in a similar manner to the diagrams of total weights. For instance, the finished weight of the shell plating in a steamer follows approximately the formula—

$$w_s = c_s N^{1\cdot45}$$

Where w_s = weight in tons of shell-plating to upper edge of sheer-strake.
c_s = a co-efficient, varying between 0·000112 and 0·000144.
N = Lloyd's longitudinal number.

The weight of shell buttstraps may be calculated in percentage of the weight of the shell, excluding buttstraps, thus :—

$$w_p = \frac{c_1}{L_p}$$

Where w_p = weight of buttstraps in percentage of shell weight.
L_p = average length of shell-plates in percentage of the length of the vessel between the perpendiculars.
c_1 = a co-efficient varying between 40 and 50.

The weight of timber and outfit varies in vessels, with similar specifications, almost directly as the longitudinal numbers.

DISCUSSION.

Mr. Robert Thompson (Member): Sir William White and Gentlemen, I have very great pleasure in speaking on this paper. It is short, but I think the truth of your remark on Sir Edward Reed's paper is proved by this paper to-day, as the writer of it was a member—an original member—of the North-East Coast Institution, and he has shown by the fact of his coming from Gothenburg that naval science is cosmopolitan, that the influence of this Institution is world-spread, and that we are all working for one object, namely, the extension of that knowledge which will produce the best ship for seagoing qualities. This is desired by everybody. This system of Mr. Johnson I know from experience—because Mr. Johnson was for some years with my firm—is very accurate. Taken along with another formula he had for freeboards, you rapidly arrive at the dimensions required for a given ship. The difficulties of applying the system are shown by Mr. Johnson in the latter part of his paper, where he refers to "Any difference in extra scantlings," &c. This difficulty is also accentuated by the variation in scantlings of the different classification societies, which are continually changing, and this must be taken account of in working up the weight of a ship from the formula set forth. I would further add that, so far as Mr. Johnson is concerned, I have found his calculations very accurate, and this formula is very accurate, and gives readily and quickly the weight required for any given steamer. I have appreciated very much the methods which Mr. Johnson has put before us this morning. Of

course it is an approximation for a certain type of steamer built for a certain style of registration or the specifications of a certain builder. The only real method by which we can arrive at the weight, of course, is to go into it in detail, but that is a long and laborious operation. By the formula he has given for flush-deck vessels, and having the approximate co-efficient, it is easy to arrive at the approximate weight in a few minutes. You may take the deck erections, whatever those may be, and add those on to your conclusions. I have not had the opportunity of going into these figures until I saw them here, but I think that Mr. Johnson has given us something which is a very rapid and approximately accurate measure of hull weights.

Mr. B. MARTELL (Vice-President): Sir William White, Ladies and Gentlemen, I regret very much that I am not prepared to speak on this paper as I should like to be, not having had an opportunity of seeing it before. With regard to the method of approximating to the weight of hulls of vessels, of course you know there are two or three methods, but this method of doing it by these numerals is very easy; you can arrive very quickly at the approximate weight of the hull for any particular type of ship, which is a matter sometimes of considerable importance to shipbuilders. Of course, a great deal of care should be taken in getting out the particulars of a large number of ships to see how this formula is applicable to them, as, in fact, we had to do in arranging the numbers for the scantlings of vessels. We had to take some hundreds of ships, and those numbers were so modified that we were enabled to arrive at numbers which would apply to the particular dimensions of ships, and we could adopt the scantlings to that in a very quick manner, and I do not see why the same thing could not be adopted in arriving at the weight of the hull, as is here proposed. I am very pleased to bear my testimony to the value of this paper, which is so very simple, and, I think, will be very beneficial. With these curves to guide one in this way, it is a means of graphically describing it, and any other number of intermediate-sized vessels can be got out on this curve of sections, and the thing can be made perfect for any size of ship or any type of ship. I think it is of considerable value, and great credit is due to Mr. Johnson for placing it before us.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Perhaps I may be permitted to say a word or two which could be, I have no doubt, much better said by gentlemen familiar with this type of steamer than by me. What Mr. Thompson has said indicates the practical utility of having information tabulated in such a form as this. The problem put before the private shipbuilder, so far as my information goes, is very often to give an answer by return of post which will commit him to an absolute contract; and to have information in such cases readily accessible and closely approximate to accuracy must be of enormous value. Mr. Johnson has not merely given us the result of a series of laborious calculations, but very valuable results of experience; and a very noticeable feature of recent years is the readiness with which leading shipbuilders are prepared to put their recorded information and experience at the disposal of the profession, and there is no more noticeable instance of that (I say it with some diffidence in his presence) than Mr. Thompson himself, who, when he was President of the North-East Coast Institution, put before that Institution a mass of information which I have never seen approached in any publication, and which must have represented years of work and experience on the part of his firm. He does not stand alone; that is a representative case, and I think it speaks well for the breadth of view and liberality of the private shipbuilders of this country that they should communicate facts in this fashion, keen as the competition must be in matters of business.

Mr. J. JOHNSON (Member): The points raised in the discussion are not of such a nature that

they call for any special reply. I am much indebted for the way in which you have received my paper.

The CHAIRMAN (Sir William White, K.C.B., LL.D., Sc.D., F.R.S., Vice-President): Ladies and Gentlemen, we shall record as usual a vote of thanks for this paper. I wish it to be understood that there is to be no formal conclusion of our proceedings at the meetings to-day: that will take place at our dinner to-night, when the President is in the chair. We shall then be able to renew our welcome to our foreign guests at this Congress, the success of which I think is now assured.

CRANK AND OTHER SHAFTS USED IN THE MERCANTILE MARINE.

By G. W. MANUEL, Esq., R.N.R., Member.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; Sir NATHANIEL BARNABY, K.C.B., Vice-President, in the Chair.]

I HAVE selected this subject, as the failure and breakage of shafting in the Mercantile Marine, though not so frequent as formerly, still goes on, as recorded by the daily papers, causing loss and detention to the shipowner and anxiety to all concerned.

While bringing before you the cause of some of those failures, I take this opportunity of getting the experience of those of our foreign colleagues now visiting us, on this important matter.

Papers have been read and discussed, here and elsewhere, connected with this subject, chiefly dealing with the calculations relating to the twisting and bending moments, effects of the angles of cranks, &c.

It is not my intention to trouble you with calculations on this, your Jubilee trip, but rather to give you the results of experience of the working of these shafts, under the calculations already made for us by the Board of Trade and Lloyd's Register of Shipping, which govern the minimum dimensions of all these shafts in the Mercantile Marine of this country, and also some of the causes of the breakage of these shafts.

I will begin by allowing that all shafts fitted in new steamers are likely to be in line, and fair with one another from crank to propeller shaft, when the completion of coupling-up is done after the steamer is launched and is water-borne, therefore I do not take fitting of this description into account.

After the bearings are adjusted, engines set to work, the voyage begun, and the power to give the required full speed exerted, then, owing to insufficient bearing surface, the oil for lubrication gets squeezed out, and the metal of the shaft and bearings gets too close together, causing excessive friction; hot bearings commence, and, it may be, one or two bearing nuts are slacked back, and salt water, as well as oil, used for the rest of the voyage, causing the bearings to get rough, the shaft is strained by alternate bending, heating, and cooling suddenly, and, when this is continued, it gets

out of line; fractures begin, until the shaft breaks at sea, or has to be taken out on arrival in port.

I have known the crank pin bearings, under these circumstances, require renewal after a voyage of only 6,000 miles, in spite of many gallons of oil wasted, and the main bearings require to be lined up after running half that distance.

The failure in this case is due to the engine-builder, who also may have had pressure put on by the owner to get the engines into as little space and made as light as possible; added to this there is the rivalry due to competition with other builders.

Shaft Bearings Getting Hot.

Allowing that the bearing surfaces are of good proportion, damage to shafts occurs from want of proper lubrication, or dirt and grit getting into the bearings, and the engine not being slowed down or stopped in time, before the heat becomes so excessive as to melt the bearing metal. Cold sea water is suddenly applied while the surface of the shaft is expanded by heat, causing surface flaws to commence by sudden contraction locally, or hidden flaws to open out, especially where the shaft is made of non-homogeneous material; these may eventually cause it to give way, or to be renewed in harbour. Figs. 1, 2, and 8 (Plate XVIII.) show some hidden flaws which have come to the surface.

The failure in this case is primarily due to want of judgment, or neglect, on the part of the engineer or men in charge.

Unequal Loading of Cargo.

It has sometimes occurred when loading vacant parts of holds adjacent to the engines, that hundreds of tons of metal blocks or bars have been put in a short space, with ordinary light cargo in same hold; the steamer's hull becomes locally deflected with such treatment, also the shaft, and under the influence of heavy weather the shaft is strained and flaws commence, ending as before.

This failure is due to want of consideration by those in charge of the stowage of the vessel.

I would here mention that weak engine seatings, defective bearings, brittle steel bed plates and framings supporting the engines, have caused the breakage and failure of shafts.

These latter failures are due to ship and engine-builders' designs.

Twin Screw Steamers.

It is well known that engines in these steamers, originally designed to lessen the danger of accident, have not lessened the breakages of their shafts, though they have enabled vessels, after the shaft of one engine has given way, to make their port with the other engine.

I refer more particularly to the large class of ocean steamers and also the smaller class, both having large horse-power.

In some cases the shafts have been insufficiently supported by the ship's hull, at a considerable distance from the centre of the vessel transversely, and the destruction of the shaft is eventually caused by this and by the bearings being far apart, and by the screw-shaft being unprotected and exposed to shocks of the sea in bad weather, as well as by the continual strains due to vibration of the ships themselves, which is, in some cases, considerable, causing alternate elongation and compression in the direction of the length of the shaft, and creating flaws on the surface circumferentially close to couplings and bearings, that eventually cause the destruction of the shaft. (Fig. 6, Plate XVIII.)

These failures are due to inefficient design of hull and bearings at the stern part of the vessel.

Hollow Shafts.

Hollow crank and screw shafts have been seldom used in ocean-going steamers of the Mercantile Marine; and excepting a test hole bored by the manufacturer in the centre of steel shafts forged from the ingot, to ascertain if there is any cavity, or what is termed piping, in the centre, which hole does not exceed $2\frac{1}{2}$ in. diameter in large shafts, these shafts are generally solid. Shafts usually give way from flaws near the surface, and would give way earlier at sea if they were hollow and not supported by the metal next the centre. I have seen several solid shafts, with serious flaws extending inwards 3 in. from the circumference, bring the vessel full speed into port, whereas if made hollow they would have broken at sea. In cases where some hollow shafts were used they gave out at sea. Fig. 3, Plate XVIII., shows a propeller shaft—found flawed—which I had broken.

Failures in these cases are due to design.

Where improvements have been made to remedy the defects I have mentioned, ocean-going steamers are now driven at full speed on a voyage of 12,000 miles with no salt water on the bearings for years, and free from mishaps.

I may here say that the use of triple and quadruple engines, by reducing vibration as compared with the irregular motion of the two-crank engines, tends to increase the

life of these shafts, and that part of the power formerly wasted in vibrating the vessel is now utilised in propelling it. Balancing engines also tends to prolong the duration of shafts.

In spite of all these improvements relating to design, there remains the serious question of defective and varied quality of the material which these shafts are composed of, and many have given way at sea, and also been condemned, through no other cause than original defects in material and process of construction. (Figs. 1, 2, 5, and 8, Plate XVIII.)

Shafts Made of Iron.

Iron is now less used, especially for crank shafts; steel is gradually taking its place in ocean-going steamers, except for propeller shafts.

Iron shafts are, I may say, made up of thousands of small pieces of selected iron, generally termed scrap, cuttings of old iron boiler plates, good navy ship iron, cuttings off forgings, old bolts, horse shoes, angle iron, all welded together, forged into billets, re-heated and rolled into bars, cut into lengths, and formed into slabs of suitable size for welding up into the shaft. Before the general use of steel considerable improvement on the old method of faggoting, so-called, had been made, more powerful forging hammers used, along with more suitable furnaces and fuel; still, with all this care, I may say there is not an iron shaft without flaws or defects, more or less, and when these flaws became placed, during the construction of the shaft, in proximity to the greatest strain, even though there was no hot bearing (which no doubt would have made matters worse), they often extended until the shaft became unseaworthy. After all, using the best wrought iron that could be made of the finest scrap from the best qualities of selected brands, iron shafts are 60 per cent. inferior in strength to the best mild steel made on the open-hearth system, cast into ingots, and forged down under the hydraulic hammer or press. (Figs. 1, 2, 5, and 8.) Fig. 5 shows a section of the unwelded faggot bars. This shaft broke at sea.

Shafts Made from Forged Steel Scrap.

After the introduction of mild steel for the construction of vessels there resulted an accumulation of cuttings from ships' plates, &c., and it was then considered desirable and economical to work this scrap steel into piston rods and shafts. But shafts made in this manner, though stronger than iron, as regards tensile strength, contained similar defects to those of iron; also the material was unequal, and was in some parts hard, and in others soft; moreover, as they were made up of thousands of pieces of different steels, and as dirt, &c., was present, and also as steel requires more

care in welding than wrought iron, the shafts and piston rods made in this manner were found inferior to those made of good homogeneous steel forged from the ingot, or even good wrought iron, and some gave way.

Shafts Made from Cast Steel.

I may here state that, in the P. & O. Company's service, steel forged from the ingot was used for crank shafts as far back as 1863; it was then manufactured in Prussia by Messrs. Krupp, and generally known as Krupp's steel; the tensile strength was about forty tons per square inch, and, though free from flaws, these crank shafts broke without warning. This steel was too brittle to withstand the strains of the engines, and its use was discontinued in the service and iron shafts again resorted to. (Fig. 7, Plate XVIII.)

Great improvements have been made by Messrs. Krupp since then, and I am informed that their shafts are now of excellent quality.

Shafts Made of Cast Steel, Unforged.

Attempts have been made to manufacture crank and other shafts machined direct from the mould after being annealed. The result generally ended in failures, as the material was wanting in that ductility and toughness necessary in crank and other shafts, and I think they are now seldom used.

Mild Steel Forged Shafts.

The term mild steel applied to shafts in a general manner does not, in my experience, represent the condition of the shaft, for I have found there are very great differences in the value and quality of mild steel, even as much as I found in wrought iron, depending largely on the qualities of the iron used, the chemical and moulding operations of converting it into steel, and also the amount and description of mechanical work applied when it is being forged into shafts. I attach tables showing these differences by actual test (Tables I. and II.).

Mild steel was first used by the P. & O. Company in 1880. The dimensions of the shafts were limited by the same rules as those for wrought iron shafts.

The steel was made by the best makers, having a tensile strength of 24 tons per square inch, it being then considered inadvisable to exceed this limit on account of former experiences with steel of high tensile strength. The shafts made were crank shafts, and are still running, having been in use seventeen years; up to the present date no flaws of any description have been seen. The engines have been tripled, using

the same shafts and bearings, and the working power increased. The percentage above the Board of Trade and Lloyd's rules, which fix the minimum size, was 24 per cent. A percentage above the rules must be allowed, and this has been the experience of all shipowners, and arises from their record of mishaps and losses, and condemnation of shafts by the surveyors of the Board of Trade and Lloyd's Registry.

Since these shafts were first used the tensile strength of mild steel has been gradually increased, and we are now using it at 32 tons per square inch, possessing equal, if not more, ductility and toughness, and able to endure even greater strains than formerly. This has been arrived at by continued improvement in the manufacture by the steel makers, so that the percentage allowed above the rules is gradually reduced to only 6 per cent., leaving a very slight margin (Table III.). I mention this as there is an opinion that the reason some shafts are so free from mishaps is owing to their dimensions being so much above the rules that regulate those sizes, instead of to the superior quality of the material used (Table II.). The Table given shows the results of steel tests made from 1880 up to the present time, independently of those made by the Board of Trade and Lloyd's, which you will find interesting.

Propeller Shafts.

These shafts, until lately, have mostly been made of good wrought iron; steel, where it has been used, in stern tubes and outside, where exposed to the action of sea water, has in many instances been reduced in diameter in a very short time, and in some cases the shafts have given way, and in others they have had to be taken out through corrosion. Figs. 3, 4, and 9 show the position of flaws.

There is no doubt that steel, when exposed to sea water, corrodes more rapidly than wrought iron. Where steel is used and protected from the action of sea water it can be employed with advantage. Different methods have been adopted to protect the steel. I give you one which has been so far successful for large shafts. (Fig. 9, Plate XVIII.)

The best method would be to make the gun-metal covering in one piece, but this is an achievement not yet reached in large marine engineering practice. I regret to state, broken screw shafts have been on the increase.

Before explaining the diagrams and tables I would add a few words about nickel steel.

Nickel Steel.

This has been lately used for the construction of shafts, and, while possessing a higher tensile strength—about 40 tons—it also possesses increased ductility and toughness. But, as the price of this material is above that of the best mild steel, the

shipowner would gain nothing by its use, unless a corresponding reduction were allowed in the diameter, and consequently the weight, of the shafts, for which purposes a modification of the rules of the Board of Trade and Lloyd's would be desirable; this should only be granted on condition that a more severe test be applied than those in use at present, so that good and bad steels may be more easily distinguished. I do not wish to undervalue the tests instituted by the Board of Trade and Lloyd's Register, which have been most valuable; but, on account of the great advancement in the quality of steel, a more sensitive test is required.

In 1881, when mild steel was coming into use for shafts, in order to compare its value with the usual and best wrought iron, I had test pieces cut out of iron and steel shafts, made to the same dimensions, and tested in the same manner (Nos. 1, 2, 3, and 4); the dimensions were $1\frac{1}{4}$ in. square by 13 in. long, as per sketch (Plate XIX.), which shows the method in which the tests were applied.

No. 1, cut from a rolled bar of best Staffordshire iron, not machined, broke at one blow.

No. 2, cut from large chain iron, forged down to size and machined, broke at twenty blows.

No. 3, cut from a new best wrought iron crank-shaft forging, "machined only," broke at eleven blows.

No. 4, cut from a new best mild steel crank-shaft forging, and "machined only" stood sixty blows before breaking.

These simple tests showed the great superiority of mild forged steel above that of the best forged iron for the construction of shafts. Tables I. and II. give, up to present time, more particulars of these tests of wrought iron and steel. Table III. gives the gradual reduction of the factor of safety to present date.

TABLE I.

TESTS OF WROUGHT IRON USED FOR SHAFTS.

Year.	Tensile Strength. Tons.	Elongation in 5 in. per cent.	Bend.	Fractured. Blows.	Broke. Blows.	Fall of 10 cwts. In inches.	
1881			Ordinary shafts.				
	18	22	Good	9	11	12	Crank
1881			Best double rolled scrap 4½ cwt. blooms.				
	18·6	24·3	Good	17	18	12	Crank
1881	Best iron, three good qualities, rolled into flat bars, and cut into 4½ cwt. blooms.						
	22	25	Good	21	32	12	Crank
1896	22·9	23	Good	12	14	12	Thrust
,,	21·9	25·7	,,	15	21	12	Propeller
,,	22·3	26·7	,,	12	19	12	Crank
,,	22·4	28·6	,,	22	30	12	Propeller
,,	24	27·6	,,	20	28	12	piston rod, 10" dia. B□

TABLE II.

TESTS OF STEEL.

Year.	Tensile Strength. Tons.	Elongation in 5 in. per cent.	Bend.	Fractured. Blows.	Broke. Blows.	Fall of 10 cwts. In inches.	
1881	24	—	Good	52	60	12	
,,	27	25·9	,,	76	81	12	
1893	28	21	,,	26	32	12	F O
1896	29·1	26·1	,,	67	80	12	C ±
,,	29·6	28·4	,,	71	78	12	
,,	29·7	27·1	,,	70	86	12	D +
,,	*30·7	25·2	,,	75	89	12	A +
,,	32	26	,,	70	89	12	
,,	33·2	26	,,	74	84	12	

* After being nicked all round with a chisel, this piece (A) was broken under a heavy hand hammer and stood 22 blows.

TABLE III.

Year.	Percentage of Strength above Board of Trade Rules.	Tensile Strength. Tons.	Material.
1879	26	18	Wrought Iron.
1881	24	24	Steel.
1887	14	28	,,
1892	11	31	,,
1897	6	32	,,

I have some specimens here to show you, from which you will readily distinguish good and bad material, both in wrought iron and steel.

After an experience of steel shafts for sixteen years, I have neither flaws nor breakages to report, while I have gradually reduced the margin of safety of these steel shafts from 24 per cent. to 6 per cent.

I conclude by stating that, amongst the many improvements in marine machinery made during the last sixty years, none has added so much to the safety and efficiency of ocean-going steamers as the manufacture of mild forged steel made by the best English makers.

DISCUSSION.

Sir JOHN DURSTON, K.C.B., R.N. (Vice-President): Mr. Chairman, the chief value of Mr. Manuel's paper I take to be in those tables in which he has given the results of the tests which he has applied to steel and iron of which crank shafts and propeller shafts were made. Turning to the remarks on twin-screw steamers, Mr. Manuel says, "It is well known that engines in these steamers, originally designed to lessen the danger of accident, have not lessened the breakage of their shafts, though they have been able, after the shaft of one engine has given way, to make their port with the other engine." That is one of the objects of having twin screws, and the twin-screw system justifies its adoption from that point of view. Then Mr. Manuel has referred to hollow shafts, and he has given us an example where the shaft is eaten right away to the hollow part in the centre, when, of course, the shaft gives way. Well, if you apply that to the hollow shaft, you would have to assume the solid shaft to be eaten right through, and, of course, then the result comes to the same; but we have a large experience of hollow shafts in the Navy, and so far they have been satisfactory. We have had no accidents with them, and we believe that we get, by making them hollow, a better material, and a better worked material, through the portion of the shaft remaining. However efficient processes of manufacture may be, I think it stands to reason that more work can be put into

the substance of a hollow shaft, if properly made, than into a solid one. We are obliged to Mr. Manuel for his drawing attention to various points as to the making of shafts of homogeneous material, and getting over the trouble from piston rods, especially now, with the greater use of metallic packing, which has a greater wearing effect on the surfaces than soft packing. As to the preservation of the shaft by coating, I take it the same thing would apply as to the coating of a ship's bottom, that if you apply the preservative material while the shaft is dry, and give the material sufficient time to dry and harden, that material will be more effective and last longer than if otherwise applied.

Mr. W. M. McFarland, U.S.N. (Visitor): It is hardly worth while for me to go on the platform, as I have really nothing to add. I was going to ask the same questions as Sir John Durston with regard to hollow shafts, only I was going to ask Mr. Manuel if he is opposed to hollow shafts. It would almost seem from the paper that such is his position. He speaks of the great toughness due to mild forged steel, but even there he does not say anything about hollow shafts. Of course, as Sir John Durston has remarked, in the Navy all the shafts are hollow, and in our comparatively limited experience in America (as compared with the British Navy), they have done very well indeed, and we have never had any trouble.

Mr. J. T. Milton (Member of Council): I will preface my remarks by saying that I think the Congress is very much indebted to Mr. Manuel, a very experienced engineer, for coming here and giving us the result of a lifetime of careful consideration of all kinds of facts which have come before his notice in regard to shafts. I will confine myself to a few remarks upon what Mr. Manuel has so graphically put before us as to some of the failures which have occurred with shafts in general use. First as to rules for sizes. No rules, either Board of Trade rules or the rules of Lloyd's Register, will prevent failure of shafts if they are allowed to get out of line, or to run with hot bearings and then have cold water put on them. One way to get over difficulties with shafts is to give careful attention to them, and examine them frequently, watch for the first appearance of flaws, find the reason why they come, and try to prevent that reason from recurring. When we come to some of the points of Mr. Manuel's paper, I will say at once that I think that he does not give sufficient credit to the improved method of manufacturing crank shafts. He has told us during the last few years the failures of crank shafts have been very much fewer than they used to be. He attributes this to the triple-expansion engine. My experience is that the improved lifetime of crank shafts is due, in a great measure, to the fact that now, in nineteen cases out of twenty, the shafts are built shafts. In the old days they were the ordinary solid shafts. Now, with a built shaft we get very much better material, because the effect of the hammer can reach every part of it. Then the pieces are smaller, and are more under the control of the forgeman. The great difficulty in shafts at the present time, however, is not with crank but with screw shafts. Fortunately for Mr. Manuel, he appears to have had very little experience of those failures. His fleet has been remarkably free from accidents to screw shafts. The majority of accidents to screw shafts occur in vessels known as tramps, ordinary merchant steamers engaged in general trades. When a shaft has failed it is very difficult to put your finger on any one point and say, That is the reason why that shaft has broken. There are so many reasons for failures, especially in screw shafts. One of the reasons Mr. Manuel has mentioned is the fact that you do not get homogeneous material. It naturally follows that, if your shaft is made out of some thousands of pieces, some of the pieces may be very ductile, while others are wanting in ductility. When the strain comes on the shaft, the stiff pieces take most of it, and the ductile pieces shirk their work. If this is so, the stiff pieces have to break, if they cannot stand the strain; and thus fracture commences, and it very soon follows through the section. In Mr. Manuel's remarks on

shafts made of iron, he has given us the way they ought to be made. He says: "Iron shafts are, I may say, made up of thousands of small pieces of *selected* iron, generally termed scrap—cuttings of old iron boiler plates, good Navy ship iron, cuttings off forgings, old bolts, horse shoes, angle iron—all welded together, forged into billets, re-heated and rolled into bars, cut into lengths, and formed into slabs of suitable size for welding up into the shaft." That is how they ought to be made, but I think he might have said that many are made without the intermediate process, after being forged into billets, of being re-heated and rolled into bars, cut into lengths, and formed into slabs of suitable size for welding up into the shaft. Many shafts are made from pieces of metal of very different qualities, without much selection, just as they are taken from the piles of scraps, made into blooms, which are then used to make the forgings of. I do not agree with Mr. Manuel on one or two other points regarding manufacture. For instance, he says, with regard to shafts made of forged steel scrap, "Shafts made in this manner, though stronger than iron, as regards tensile strength, contained similar defects to those of iron, also the *inequality* of the material, &c." In my opinion a forged steel scrap shaft is of far more equal quality, throughout, than you are likely to get in an iron shaft. The ordinary scrap iron of commerce is not a uniform material. Mr. Manuel says it is made of old iron boiler plates, good Navy ship iron, cuttings off forgings, old bolts, horse shoes, angle iron, all welded together. There are many qualities of iron found in ordinary scrap besides those he has mentioned, and there are greater differences in the quality of the separate pieces of iron than you will find in the quality of scrap steel. The ordinary ship scrap steel, being all from tested steel, is very nearly of uniform quality throughout. There is a point Mr. Manuel has not mentioned, where he says he finds that "shafts and piston-rods made in this manner were found inferior to those made of good homogeneous steel forged from the ingot." When we speak of steel forged from the ingot, we must remember that ingot steel may be 28, 30, 32, or possibly 36 tons steel, so that merely speaking of ingot steel does not define what quality of steel you get. While we are on the subject of the quality of steel, I see Mr. Manuel appears to recommend the use of hard steel for shafts. He shows us that in some of his tests in Table II., he gradually progressed from a tensile strength of 24 tons to a tensile strength of 33 tons. There is one peculiar point to notice, if you look at that table—27 ton steel breaks at 81 blows, and 33 ton steel stands only 84 blows. So I think in these tests the hard steel shows no appreciable advantage over the ordinary mild steel of 27 tons. I must admit myself, if I had the choice, I should prefer mild steel of 30 tons as the maximum, to anything approaching 33 tons. I have had some experience where harder steel has been used, where the tests have shown fairly good ductility, but it had nothing like the endurance of good soft steel, and, I think, it is generally agreed that one of the first firms who started making steel shafts in this country built up their reputation for the very superior quality of their shafts through using the very mildest steel they could obtain. With regard to some of these other tests, will you please look at Table II. and Table I. These show one important point in regard to steel, generally, compared with iron. They show that the fracture commences in either, before actual separation takes place. I believe in steel, generally, a fracture once started extends more readily than in iron, and more readily in hard steel than in soft steel. If you look at one example on Table I., whereas it took twenty-one blows to start a crack in wrought iron, it took thirty-two blows to finally break it. Taken generally right through the table, it takes 50 per cent. more blows to actually separate the pieces of iron than it takes to commence the fracture. When you come to look at steel, you find that is not the case. It is evident to me that iron takes longer to break up after it has once begun to crack than steel does. This brings me to the question of nickel steel. One of my colleagues, some year or more

ago, tested some nickel steel as against some of the best ordinary mild Siemens steel, and also hard Siemens steel made into large forgings. He tested the pieces in the way Mr. Manuel has tested them, viz., by the fatigue test, which is an admirable way of testing. When the test pieces were planed in the ordinary way there was very little difference in the number of blows required to break nickel steel, or to break mild steel, or the hard steel. There was not much to choose between these materials from the results of those tests, but when the test pieces were nicked in there was a most wonderful difference in the behaviour. Speaking from memory, the hard steel—thirty-six tons—broke with the first blow of a half-metre fall; the softer steel stood two or three blows: but the nickel steel took sixteen blows from the height of a metre, and three or four more from a metre and a half before it broke. Comparatively early in the test, say, after six or seven blows, it began to crack, but the fracture was a gradual one, increasing slightly with each successive blow; whereas, with the carbon steel, when it begins to break, it goes through with a snap. Mr. Manuel has given us a sketch of a screw shaft showing four serious flaws in it. Unfortunately, it is a very common experience to find shafts which have been in use two, three, and four years, and sometimes even less, with some of the flaws shown in Mr. Manuel's figures. I have never come across one with all four, but such a thing is not by any means improbable. Mr. Manuel suggests that the way to prevent these flaws is to make your liner continuous instead of dividing it into two pieces, and he shows us the way that is adopted in his company for doing this. I am sorry he does not say how he gets over the flaw at the front end of the shaft. The defects indicated by Mr. Manuel are giving marine engineers a very great deal of anxiety. I have been working on the subject myself, and have got a great many statistics of the life of shafts, but I am sorry that, with all my trouble, I have not been able to put my finger on that which caused the flaws. My opinion is that there are very many causes at work which produce them. One of them is undoubtedly that which Mr. Manuel mentions. Corrosion sets up at the junction between the brass and the iron. If the shaft begins to be weakened there, naturally, when it is subjected to undue stress, there is a greater intensity of stress where the shaft is smaller, and, if the stress is sufficiently severe, rupture commences to take place there. But, from the nature of the flaws, I feel sure that what actually causes the separation of the molecules of the iron is a longitudinal stress; it is not solely the torsional stress. I think it is mainly due to the bending action in the shaft. Where abrupt changes of form come on the shaft, you must expect a concentration of the stress, and when once rupture commences, it will more rapidly extend, if there is a want of continuity of form at the locality of the crack; and, unfortunately, where you shrink a strong gun-metal liner on a shaft, you must have the want of continuity where the liner ends. If any bending does come on the shaft, the part at the end of the liner will necessarily get more strained. I have recommended our Committee to suggest to engineers, generally, that they should make the liners a little longer, and taper them down as thin as they can while keeping them tight. (If you make them too thin, you will not get them tight at the edge.) There is another advantage in this. If shafts are often looked at, and you find incipient corrosion just commencing at the edge of the liner, you can cut off a part of the liner, and remove part of the cause from the weakened spot. By far the greater part of the shaft failures is due, I think, not to the manufacture of the shaft, nor to the size of the shaft, but to the use to which the shaft is put. It is a singular thing, but certain ships, running in certain trades, are what engineers call very hard on their shafts, while shafts on ships in other trades last for many years. Mr. Manuel says that their shafts are examined every four years. I should be very sorry to let some steamers run four years without looking at them, myself. Mr. Manuel's ships, and very many other ships, are subjected to hard, driving work, steady

strains on the shaft, but they are all loaded down in their ordinary trade, and not exposed to the same conditions as the tramp steamers. Very many tramp steamers, engaged in very heavy trades, make voyages of hundreds of miles in ballast. The modern tramp steamer in such a condition is like a bladder on the water. The screw is only about half immersed, and at every revolution of the engine the striking of the blades on the water brings four blows on the shaft, even in smooth water. What happens in dirty weather on the Atlantic? I think that a great part of the fatality of shafts is due to the exigencies of such trades. From the particulars I have obtained it appears that the greatest number of these fatalities occur in the ships which are subjected to that class of work. I think I have really gone through all the points which occur to me just at the moment. I think we ought to be very thankful when a gentleman like Mr. Manuel, of so many years' experience, comes forward here and gives us his views on such matters. It must be very gratifying to anybody who travels in the P. & O. ships to find that they are so free from all kinds of defects.

Mr. J. I. THORNYCROFT, F.R.S. (Vice-President): I will confine myself, I think, almost to one point. What Mr. Milton has said shows that continuity of section is very important, and I think in this he has really put before us one of the most important of the points. He has also shown us that, in considering the uniform turning moment of the engine, we have not got over all the difficulties. In the tramp, where the propeller strikes the water three or four blows per revolution, owing to want of immersion at light draught, you have a sudden change in the resistance of the propeller, which, taken with the inertia of the moving parts of the engine, subjects the shaft to a varying stress which is a cause of trouble, accentuated by any change of section in the shaft. Mr. Milton has told us, what I believe Mr. Manuel has also brought before us, that it is desirable to taper the ends of the liner sprung on to the shafts, and Mr. Manuel has told us that the effect of that has been found to lessen the tendency to corrosion where the liner finishes. I think Mr. Manuel says that the stress put on the shaft is mostly longitudinal. He considers the cracks to indicate that. I am not myself very familiar with these cracks, but I would point out that, when a strong envelope is put on the shaft, from the nature of the problem it amounts to this, that although the gun-metal may not be so stiff as the shaft, from the fact that the stress on an equal material tends to increase exactly with the radius, the stress coming on the gun-metal, due to the fact that it is shrunk on, makes a want of continuity due to its connection with the shaft, and we get, at the point where it finishes, much greater stress at the surface of the shaft, and therefore a want of protection leads to corrosion, due to the change of the tortional stress. I think that the suggestion of making the tapering ends longer is important, and should have the greatest attention. I would further remark that, with regard to shafts, I think there is a cause of fracture which has not been sufficiently considered, and it amounts to what pervades most things, that where you get oscillation coincident with the natural period of vibration, the stress may increase very largely. In the shaft, either due to the propeller or the engines, you always will have at times an oscillation in the turning moment which the shaft has to bear. The shaft then twists momentarily to a certain extent, and if it so happens, owing to the length or other dimensions of the shaft, that the period of oscillation of the shaft agrees with the cause of vibration, in that case the ordinary rules for calculating the strength of the shaft will not indicate, with any accuracy, the amount of force coming on them. At present I have not been able to investigate this question, but I think it is one that would repay investigation, and I have called the attention of our members to it, because, if anybody would take up the subject, I think it might be fruitful of much advantage. I think we may congratulate Mr. Manuel on the fact that, owing to the tests he has put on the steel, he has had such success with his shafts.

Mr. Alfred Holt (Member): I wish to confirm Mr. Thornycroft's remark that the real cause of shafts breaking is the strain that is put on them by the propeller. We have been in the habit of calculating the dimensions of our shafts in terms of our engines; my idea is that we should calculate them in a certain measure in terms of our propellers. I have no doubt that if our steamers had only to do regular work, such as that of turning the machinery of a cotton mill, we should never hear of broken shafts. It is the strain arising from heavy pitching in a seaway which, as Mr. Milton has stated, produces these accidents. I think (for I have not the figures before me) that there were at one moment twenty-three vessels knocking about in the North Atlantic during the past winter with broken tail shafts, mostly tramp vessels, which, having only water ballast, were like haystacks on the water, and pitching in this condition their screws were brought with immense violence into contact with the surface of the waves from great heights: I daresay sometimes 17 to 20 ft. The solution that I have come to of the question is, to have your propeller as small as you can consistently with other circumstances. Everyone present connected with steamers must know the immense diversity there is in good shipbuilders' practice as to diameter of propellers. I have known vessels of equal size and horse-power with 4 ft. difference in the diameter of the propeller. It is quite clear that the larger propeller must impart a very much greater torsional and also bending strain to the shaft than the smaller one (totally irrespectively of the horse-power), and my moral would be, try to use as small propellers as is consistent with other relevant circumstances. I have known instances of 17 ft. propellers breaking about 3 ft. off the tips of the blades, which is synonymous with reducing the diameter by 6 ft., and the ship going along perhaps better. We overdo size in our endeavour to get disc area.

Mr. A. E. Seaton (Member of Council): I was struck with a remark made by Mr. McFarland yesterday in that practical manner which distinguishes his nation. He said that instead of seeking out mysterious causes for phenomena we should look for them under our noses. I think that may be applied to questions about shafts. There is no mystery whatever about these things, in my opinion. The fractures are due to perfectly obvious causes, most of which have been touched upon by the speakers to-day. The question of broken shafts occupied my attention many years ago, when the Board of Trade first formulated their rules. Many of those present will remember that it so happened that one particular ship in the published list had a very much larger shaft in proportion to the size of engine than any other. I know that ship very well; no ship broke her crank shafts quicker than she did. I think the reason why we have better results from steel shafts to-day is not so much due to that material as to the fact that much greater attention is paid to the designing of the main framework and bearings of the engines, and to the material of which they are made. As most of the members know, soft steel will not run well on gun-metal. As a matter of fact, the mild steel of which Mr. Manuel speaks will not run at all on gun-metal at high speed. White metal has been, in my opinion, one of the chief causes for the successful running of mild steel shafts. There are many things in Mr. Manuel's paper which I do not agree with; at the same time, I fully appreciate both the spirit which has actuated him in bringing it before us and the information he has given us, because we all know Mr. Manuel is a most experienced marine engineer, and I suppose his steamers have fewer accidents than those of anyone else. But when he speaks of a 24 per cent. margin I do not admit this to be the sole cause, as in my experience this is not necessary. I do not agree at all with what Mr. Manuel says about the hollow shaft. My own opinion is that, by boring out the centre of the shaft, you get rid of all doubtful material, and remove a fruitful source of injury. Serious defects often arise from hammering into the shaft incipient surface flaws.

I know the particular firm which Mr. Milton has alluded to has always exercised the greatest care in the making of shafts; the forged surface is examined almost microscopically, and every trace of flaw cut out before the shaft is finally forged. Much has been said on the question of tail shafts. There is no doubt that what Mr. Holt said is perfectly true, that the breaking of tail shafts is due to the strain from the propeller itself. Mr. Holt is one of the few shipowners who has a sufficient knowledge of engineering to warrant him, I think, in interfering with the engine maker; it is rather singular, therefore, he has hit on the very thing in which shipowners do often interfere. There are two things about which a shipowner seems to think he has a right to dictate: one is the diameter of the funnel, and the other is the diameter of the propeller; on both those points my experience is that it is no use to argue, it is better to do as you are told. In the tramp boat one finds a huge propeller made of cast iron, and generally of such a thickness, and consequent weight, as to make it a very terrific instrument. Mr. Milton has said, very properly, that the action on the shaft by the beat of the screw blades, in a light ship or when racing, is very serious. Mr. Manuel has passed by shafts made of cast steel with contempt, but I am not aware that he is warranted in saying that the result generally ended in failure; on the contrary, I believe almost the reverse is the case. Our late lamented member, John Francis Hall, I believe, was the first to make cast steel shafts, and he was very successful; the tests made on portions of these shafts were most satisfactory, both in the ultimate tensile, bending and extension—as satisfactory, in fact, as any steel forging. I have never had a shaft of this kind, but I did have some large connecting rods of steel casting, and they have run for twelve years and given perfect satisfaction. As regards the forgings from scrap steel, I do not think we yet fully appreciate the possibilities of steel forgings from shipyard scrap. The steel used in shipbuilding is very fairly uniform in quality, and that quality is very much higher than the iron used formerly. The gun-metal covering of shafts is one of the things I think we have got to look at straight. We go on talking, at meetings of this kind, as to how it is best to cure an evil created by a system, instead of condemning the system itself. I have made a good many ships in which we have done away with the shaft liner altogether; we have simply had a steel or iron shaft running on a cast-iron or white metal stern bush. I think instead of discussing how to get over the difficulty, we should consider first whether the cause of it cannot be removed altogether. I do not suppose Mr. Manuel would like to do it in one of his big ships, but I can assure him that if he tried it with one of the tenders he would be perfectly satisfied with the result. I do not at this late hour propose to offer any other remarks, but I do think that Mr. Manuel is to be thanked for dealing with all these points.

Mr. Thomas Mudd (Member): I shall be very brief, but I should like to say two or three words on this subject. It is rather interesting to note that the discussion has turned more upon tail shafts than crank shafts or other shafts. The cause is not far to seek, because 90 per cent. of the accidents which happen to shafting occur in tail shafts. I should like to refer more particularly, therefore, to these shafts, especially as it may be known to some that my name has, for some four years, been connected with an attempt—I will put it in that way—to overcome the rate of mortality that has taken place in tail shafts, by preventing the corrosive action. I should like to say something that would rather modify, I think, the remarks of Mr. Milton when he referred to the longitudinal stresses being more particularly responsible for the mortality of tail shafts. When you add merely an india-rubber covering to a tail shaft, of an eighth of an inch in thickness, one cannot of course expect that that will, in any way, reduce anything that might take place due to longitudinal stress; but it is a fact that that indiarubber covering preserves the shaft, and hence I cannot believe the failure is due

to longitudinal stresses. After four years of use of the indiarubber coating on the shaft, I have seen many shafts examined, and found them to have absolutely no defect whatever, the skin of the shafts being as perfect as on the day when they left the shop. I have seen several shafts which have been at sea for two and a half and three years, with this device, which were in excellent condition, and that goes to show that there is really something more in it than the question of longitudinal stress. The case appears to be similar to a steel plate. For instance, if there happen to be the merest fracture in the world in the edge of a plate, and you begin to work it, failure will almost certainly take place from that starting-point. So it is in the tail shaft. The galvanic action that goes on between the brass and the iron, cuts a very fine nick round the shaft, and that concentrates the stress at that point, and the action Mr. Holt and Mr. Milton referred to, of the flapping of the blades upon the water, readily breaks the shaft at that point. Once the shaft has been nicked around by the combined galvanic and corrosive action, there is nothing more natural than that it should break there. I have in my office at the present moment a slice cut out of a tail shaft that was only at work for fifteen months, and the nick that is cut around it is about $\frac{3}{8}$ths of an inch into the shaft all the way round. An inch away from the end of the brass liner the shaft is perfect. That is a very pointed instance showing the action of corrosion, and, being connected with a place where there are several dry docks, I have seen hundreds of shafts condemned from this very cause. It seems to me the thing to do is to get rid of the galvanic action and corrosion, the initial action which enables the stresses ultimately to destroy the shaft. With regard to what Mr. Seaton said about doing away with the liner altogether, I have tried that method in two cases, but it has not been very satisfactory. One has apparently gone satisfactorily, but the other did a great deal of damage on the first voyage, and the plan had to be given up. There is also a vessel now in our dry docks—not of our manufacture—which is so fitted, and the owner has instructed us to revert to the original arrangement of brass liners, after only one voyage round the world.

The CHAIRMAN (Sir Nathaniel Barnaby, K.C.B., Vice-President): I shall now call upon Mr. Manuel to give us his reply, as briefly as he can. I am sure he will do so, seeing how limited is the time we have.

Mr. G. W. MANUEL (Member): Gentlemen, I am warned by Sir Nathaniel Barnaby that, owing to the full discussion, my time to reply is now limited, and will therefore endeavour to group those gentlemen having similar opinions on certain points together. Sir J. Durston, Mr. McFarland, and Mr. Seaton have a preference for hollow shafts. If these gentlemen will look at Figs. 3 and 4 (Plate XVIII.), there is shown a solid and hollow shaft of wrought iron, which was corroded and flawed, as shown, in the usual manner. It was a solid screw shaft; the flaw was at the end of the after gun-metal liner, close to the screw-propeller boss. The flaw is shown in black, and extended from the circumference inwards; the remaining part was uninjured, and of good material. This shaft did not break at sea; the flaw was discovered in dry dock, the shaft was taken out, and the spare shaft fitted. I had it broken on the vessel's return to the maker's works, to ascertain the depth of the flaw. It took two blows of a steam hammer to break it. What I contend is, that the sound metal towards the centre held the shaft together; whereas, had it been a hollow shaft, it would, as shown, have given way at sea, and the steamer would have failed to reach port. And my experience is that, with modern-made shafts, flaws first develop themselves on or near the surface and gradually extend inwards. I refer to the shafts in vessels of the Mercantile Marine, where the engines are driven, from year to year, at their full speed continuously. I am pleased to hear Mr. McFarland, of the United States Navy, give his experience on hollow shafts, and, as far as the Navy is concerned, they appear to have been successful.

It must, however, be borne in mind that, in these Naval vessels the engines are only run at full speed for three or four days in the year after their official trials, and under favourable circumstances, and the shafts are not subjected to continuous driving in all weathers, as in the Mercantile Marine. The fact remains that few hollow shafts have been adopted in the Mercantile Marine. Mr. Milton mentioned that, while giving some of the causes that lead to the breakage of shafts, I had not given any advice as to their prevention. I think, after giving the causes, that Mr. Milton need not go far to seek for the remedy. Take, for instance, bearings getting hot, and shafts destroyed, owing to insufficient bearing surface. The remedy is very simple, viz., increase the bearing surface until the shaft will not squeeze off the oil, but run on it; also use the best material for the construction of the shafts, &c., and so on. The difficulty is to get makers to alter existing arrangements or use the best material, and so shafts go on breaking. I quite agree with Mr. Milton that the late method of building up shafts of large size is an improvement, when carefully done and good material used, though in many cases they have given way, and the cranks have become loose on the shaft. I note his remarks on the use of shafts made from scrap steel or cuttings from ships' plates, and his preference for them above shafts made from wrought-iron scrap. I have no hesitation in confirming what I have already said regarding its unsuitableness for the construction of good, homogeneous shafts, owing to the presence of laminations and hard and soft parts, the hard eventually projecting. Similar results take place in piston rods. Mr. Milton mentioned that accidents to shafts were more frequent in vessels generally called tramps, or ordinary merchant vessels; but this should not be, and I think he forgets that the P. & O. Company have had constructed, and also acquired, tramp steamers, some carrying a few passengers, others none.

Mr. MILTON: You would scarcely call your cargo ships tramps.

Mr. MANUEL: I certainly do.

Mr. MILTON: I do not think you would like ordinary people to tell you they were tramps.

Mr. MANUEL: I do not know what else you would call them. They are tramps, in every sense of the word.

Mr. MILTON: Oh, no.

Mr. MANUEL: We had to have them in order to retain our cargo trade, and compete with outside tramp steamers, when the increased speed of the mail steamers gradually reduced the space for cargo. I have not found these shafts to break, and the Company now possesses about twenty vessels. In one instance there was trouble with one of the crank shafts through defective fitting of the cranks; it became loose. It was a built shaft. These vessels run part of their voyage under water-ballast only. I agree with Mr. Thornycroft in regard to the effects of excessive vibration on shafts, more particularly in twin-screw steamers. I am of opinion, with Mr. Holt, that keeping the diameter of the propeller down to the smallest practical dimensions for efficient propulsion lessens the strains on the screw shafts, more particularly in vessels that have to run light at times; and, when designing the propeller, it should be in accord with the diameter or strength of the shaft. I quite agree with Mr. Seaton that all mystery should be kept apart from the cause of breakages of shafts, and that these are due to perfectly obvious causes; also that greater care should be paid to the design of the main frames and bearings of the engines; but disagree in the use of white metal or cast-iron for bearings of screw shafts, also running these shafts bare on these metals without any liner on the shaft. This I have seen tried, but find there is nothing better or more durable than the use of lignum-vitæ for these

bearings, the end of the grain of the wood being next the shaft, along with gun-metal liners on the shaft, for, in spite of sand, to which the vessels are exposed in all parts of the world, these bearings will last seven to eight years before requiring lining up. Mr. Seaton mentions the factor of safety, as per Table III., in the *first* steel crank shaft in 1881 as 24 per cent. This was gradually reduced year by year to 6 per cent. in 1897, owing to the increased quality of the steel. I agree with Mr. Mudd that most of the breakages of screw shafts are caused by the action of the sea water, accelerated by the chemical action of the iron, steel, and gun-metal under pressure, which cuts deep grooves, as already explained, near the ends of the gun-metal liners, when the shafts become gradually weakened, and eventually break; but where these shafts are protected there are fewer breakages. Also that there are fewer breakages due to longitudinal strains, unless the after bearings are allowed to wear down considerably, and the shaft allowed to knock up and down in the outer bearings, as occasionally happens in twin-screw vessels, to the extent of one to three inches, causing flaws, such as shown in Fig. 6, which would eventually lead to the destruction of the shaft. I have some specimens here showing the fractures of test pieces of iron and steel; but, being again advised that the time is short for the remaining papers, I have only to thank you for the patient manner you have listened to this paper, and those gentlemen who have discussed it.

The CHAIRMAN (Sir Nathaniel Barnaby, K.C.B., Vice-President): I may thank Mr. Manuel for this very carefully prepared paper. Dr. Hele-Shaw suggests that, as he has some somewhat remarkable things to show us at the close of his paper, it should be taken last, and that Mr. Barnaby's paper should be taken at once. It is a short paper on an interesting subject, and I now ask Mr. Barnaby to be good enough to give it to us.

ON THE FORMATION OF CAVITIES IN WATER BY SCREW PROPELLERS AT HIGH SPEEDS.

By Sydney W. Barnaby, Esq., Member.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

In a paper upon torpedo-boat destroyers, read before the Institution of Civil Engineers in 1895 by Mr. Thornycroft and myself, we gave some particulars of the screw trials of the *Daring*, and described briefly the reasons which led us to conclude that a new phenomenon was manifesting itself. This phenomenon seemingly pointed to the probability that the speed of vessels was approaching a stage at which propulsion by screws would become less efficient, and we said that it appeared inevitable that reduced efficiency must be submitted to as the speeds still further increased.

If a cavity be formed in any manner in the interior of a mass of water it will tend to become filled with water vapour and with any air which might be in solution, since ebullition takes place at ordinary temperatures in a vacuum. We believed that at the speed at which the screws of the *Daring* began to give trouble such cavities were being formed, and were the source of the great waste of power and of other difficulties which were experienced.

This view met with not a little incredulity at the time, but I believe it to have been perfectly correct. The trials of the *Turbinia* and the experiments made by the Hon. Mr. Charles Parsons, and described by him to this Institution in April last, afford very strong if not complete confirmation of our contention. Even without this confirmation, the fact that the steps were successful which we took to overcome the difficulty, when we had, as we believed, discovered the cause, afforded strong evidence of the correctness of the diagnosis. As the subject may not have been brought to the attention of many of our foreign friends, I thought a short explanation of the theory of cavitation might be of interest if made as lucidly as its nature will admit and accompanied by a statement of the experience obtained with the *Daring*, upon which it is based.

Put shortly, the facts were these. With a pair of three-bladed screws 6·16 ft. (1^m,88) diameter, 9 ft. (2^m,75) mean pitch, and 8·92 sq. ft. (0^{m^2},83) developed surface,

the *Daring* attained a speed of 24 knots with 3,700 I.H.P., the screws making 30 per cent. slip. With a pair of screws of the same diameter, and practically the same mean pitch, but with a surface of 12·9 sq. ft. (1^{m^2},2)—an addition of 45 per cent. to the surface—the same speed was obtained with 650 less horse-power, and with 17¾ per cent. slip instead of 30 per cent. The number of revolutions required for 24 knots with the screws of small area sufficed to drive the vessel at 28·4 knots when the blade area was increased. The vibration was unprecedented and dangerous with the narrow blades; it was of quite a normal and unimportant character when the blades were widened.

In order to arrive at a clear understanding of what is believed to take place, it is necessary to distinguish between the two cases—firstly, that of a propeller drawing air from the surface; and secondly, that of the formation of cavities when the propeller is submerged. The effect upon the thrust of a fast-running screw when the blades break the surface of the water or when air penetrates from the surface is well known. Under such conditions the velocity at which water can flow, due to gravity at a depth h below the surface, is equal to $\sqrt{2gh}$, and amounts, for example, to only 8½ knots at a depth of one mètre.

If the velocity which has to be imparted to the water in order that it may keep in contact with a portion of the blade situated at a depth h is less than $\sqrt{2gh}$, then even if the blade break the surface, there will be no loss of efficiency. This is the case with the slow-moving, partially submerged screws used by Mr. Barcroft to propel barges on the Irish canals, as described by him in a paper recently read at the Institution of Mechanical Engineers; and it also probably explains the good results obtained with the partially submerged screws of large blade area employed in some shallow-draught tugs on the Continent. The speed at which water can follow the the float of a paddle wheel is limited by the same condition. The particulars of a large paddle steamer, having feathering wheels 20 ft. 6 in. (6^m,25) over the floats, which are 9 ft. 9 in. (2^m,98) by 3 ft. 6 in. (1^m,065), have been supplied to me. I find the slip—*i.e.*, velocity of float in relation to still water—is 11·2 ft. (3^m,41) per second. In order that the water should attain this speed, it must have a fall of $h = \frac{v^2}{2g} = \frac{11{\cdot}2^2}{64{\cdot}4} = 1{\cdot}95$ ft. (0^m,595), so that, if the top of the float was just awash when at rest, then, considering the action of one float at a time, and assuming that, at the position of the wheel, there was neither a wave crest nor a wave trough due to the motion of the vessel, the water would fall away from the back of the float when the float was in motion for a depth of nearly 2 ft., leaving 1½ ft. only immersed, as it would only be at this depth that the speed of the water due to gravity would equal that of the float.

How much the denudation of each float will be affected by the action of those in front of and behind it is very difficult to say. If it would be possible to make model experiments with a feathering wheel some useful information might be obtained.

When the screw is sufficiently submerged to exclude air from the surface the rate at which the water can be accelerated is very much greater. This can be illustrated as follows. Water will flow from a tank through an orifice discharging into the open air at a velocity depending upon the depth of the orifice below the surface of the water in the tank.

It will flow through the same orifice into the exhausted receiver of an air-pump at a much higher velocity, depending upon the degree of exhaustion in the receiver. The velocity in the latter case will be that due to the head of water plus the difference between the pressure of the atmosphere and that in the exhausted receiver. Similarly, the velocity with which water can be made to flow towards a submerged screw is due to the head of water over the screw plus the atmospheric pressure, and there is consequently a definite limit to the speed to which it can attain.

It was not easy to calculate theoretically at what point the breakdown would occur with a given propeller, but a way of attacking the problem suggested by Mr. Thornycroft proved to greatly simplify it, and to render its solution easy. His idea was that there must be a definite thrust per square inch of projected screw surface at which cavitation commenced.

A screw propels by putting water in motion sternwards. It effects its object partly by pushing the water with the after face of the blades, and partly by pulling it with the forward face. I will ask you to imagine that we have replaced the screw of a ship by a disc of rather less diameter than the screw, and that, instead of revolving the screw shaft, we push the shaft and disc sternwards at such a speed that the disc will momentarily exert the same thrust as the screw. The propelling effect would be the same as that of the screw,* and, so far as the action between the forward face of the screw blades and the contiguous water is concerned, which is what I wish to illustrate, the action of the disc affords a sufficiently close analogy. As the disc moves sternwards, it puts water in motion not only astern of it, but also ahead of it. There being no air between the water and the front face of the disc, a pull can be exerted upon the water, which is forced to follow the disc in the same manner that water is forced to follow the plunger of a pump.

But the pull which can be thus exerted by the disc is limited. At a little depth beneath the surface of the water, if the tension exceeds 15 lbs. per square inch (one

* This would not be true if the movement of the disc were continued far beyond the stern-post, but is nearly so if the movement is confined to the length of the screw.

atmosphere), the surfaces of the disc and adjacent water are torn asunder, and a cavity is formed between them.

As but a little more than half of the total acceleration imparted to the water by a screw is estimated to be produced by the suction of the forward surface, it might be supposed that a total thrust approaching to 30 lbs. per square inch (two atmospheres) might be obtained, but it appears that rupture occurs at parts of the screw surface long before the mean thrust per square inch of the whole surface reaches this amount. This is probably accounted for by the fact that the thrust of portions of the screw blade near the circumference is much greater than at portions near the boss.

By plotting the results of a progressive trial carried beyond the speed at which cavitation commenced, we were able to note the point at which the first indications of failure appeared. It is not marked by a sudden change, but by a flexure in the curve of slip, which commences to rise rapidly when the critical speed is reached.

The total thrust of the screw at this speed divided by its projected blade area gave a thrust of 11¼ lbs. per square inch (0·75 atmosphere), which is, therefore, about the maximum thrust which can be obtained from a screw working efficiently at a depth below the surface of 11 in. (0^m,28), which was the immersion of the tips of the blades in the *Daring*.* For every additional foot of immersion the total thrust per square inch may be increased by ⅜ths of a lb.

By means of the very ingenious expedient of trying a model screw in water heated nearly to boiling point, Mr. Parsons has been able to reproduce and examine the phenomenon of cavitation, and has corroborated our figure of 11¼ lbs. as the thrust at which it commences.

The difficulty of reproducing analogous conditions with a model lay in the high speed of revolution necessary; but by heating the water, and thus increasing the vapour pressure, lower speeds became possible. Since the tension of the water vapour at boiling point is equal to atmospheric pressure, a screw would cavitate in boiling water at the same speed as it would do if air were admitted to it. In other words, steam would be given off as soon as pressure was reduced. An analogous effect could be obtained by expanding by heat the residue of air in the exhausted receiver before referred to. Then the reduced difference of pressure between the air within and without the receiver would cause the water to flow into the latter from the tank more slowly, and, if the temperature of the air were raised sufficiently to cause a pressure inside

* The figure should vary slightly with the pitch ratio, being less if the latter is high, since the ratio which the suction thrust bears to the whole thrust varies with pitch ratio, but the variation is so small as to be negligible.

equal to that of the atmosphere, the rate of flow would be that due to the head of water only. The same result would be secured by using a closed tank and exhausting the air in it so that the water would flow from one vacuous region to another, and I believe, Mr. Parsons has suggested that further experiments might be made in cold water, the surface being relieved from the pressure of the atmosphere.

That cavitation will be the cause of trouble in the future is, I think, certain. Already it is becoming difficult to obtain the requisite area in screws of destroyers without either resorting to an abnormal width of blade, or to a larger diameter and pitch ratio than would otherwise have been preferable. The one expedient gives undue surface friction, and the other necessitates a reduction in the rate of revolution, and therefore a heavier engine. The fact that the designer of the *Turbinia* has been forced, doubtless against his will, to employ nine screws, in order to avoid cavitation, is an evidence of its influence and a justification of the note of warning we raised in our paper of 1895 after the trials of the *Daring*.

DISCUSSION.

The CHAIRMAN (Sir Nathaniel Barnaby, K.C.B., Vice-President): The subject is so new and so interesting that we would like to have a short discussion upon it, though one feels impressed very much with the importance of the paper which is to follow. I must therefore ask members to state their views very briefly.

Mr. D. W. TAYLOR (Member): Sir Nathaniel Barnaby, I can add nothing to the very valuable information given in Mr. Barnaby's paper, but I should like to ask him a question, to see whether he could not put us under a further obligation. I would ask Mr. Barnaby if he would explain *why* it is that cavitation should result in a serious loss of efficiency. The power wasted by the screw is absorbed, practically, by the slip, and by the friction of the surface. When a vacuum is formed behind the blade, it would seem that we lose the suction of the back of the blade, but it would seem, too, that we get rid of a part, or much of the friction of the back, so that there would be, perhaps, some gain from that point of view. I note, on page 142, that Mr. Barnaby states that the indications of failure are marked by flexure in the curve of slip, which commences to rise rapidly when the critical speed is reached. I would like to ask him if the loss of efficiency is not largely due to the increased slip accompanying cavitation, and not necessarily to the cavitation of itself.

Mr. J. I. THORNYCROFT, F.R.S. (Vice-President): Sir Nathaniel Barnaby, I think there is very little I would like to add on this paper. There is one point I would like to mention; but, before doing that, I must say that we are indebted to Mr. Barnaby for the very interesting experiment he has put before us. I feel there is one thing I must object to. My name is very largely associated with Mr. Barnaby's, but I must say it is Mr. Barnaby's work. With regard to the analogy between the propeller and the disc, I feel I must object to some extent to that, because in the case of a propeller blade it is, as it were, placing itself suddenly in a new position. Mr. Barnaby takes one disc, pushes it rapidly back, and in that case the disc is in juxtaposition with the same water for a considerable time. I think, in order to make the analogy more complete, Mr. Barnaby must imagine that, after the disc

has been moving a very short distance indeed it disappears. This is an idea which I have taken from Mr. Froude. He imagines a surface exerting pressure for a short time, and then being suddenly shifted to a new zone. I think it must be taken to occupy the same place, and not alter its distance relatively to the ship. That may be replaced by a new disc in the original position, otherwise a stream-line motion would be set up about the disc.

Mr. C. Humphrey Wingfield (Member) : The author suggests (on page 142) that a possible reason for the occurrence of rupture of the water sooner than might be expected on theoretical grounds is that, while the theory assumes a uniform thrust per unit of area of the screw blade, the actual thrust is greater at the circumference than the mean pressure so calculated. There can be little doubt that this is true, but it occurs to me as just possible that the large amount of air contained in sea-water will partly account for the observed effects. As soon as a reduction of pressure is produced in the water at the forward side of the propeller, the air tends to expand in the water, or to separate from it, and probably reduces the speed necessary to produce cavitation in a manner analogous to the action of the vapour in Mr. Parsons' experiments mentioned lower down on the same page. In referring to the latter, the author says that steam is given off from water at boiling temperature as soon as the pressure is reduced below that of the atmosphere. This is perfectly true at the surface of the water, but I think, in the case of a submerged propeller, vapour would not be given off till the pressure was further reduced below that due to the head of water above the propeller. I should like, before sitting down, to express my admiration for the very clear way in which the nature of cavitation is pictured by Mr. Barnaby's experiments. Object-lessons, such as he has put before us, teach far better than can be done by the most learned mathematical investigation. I may confess that, on first reading the expression (page 141) "a pull can be exerted upon the water," I was somewhat startled; but I recollect Lord Rayleigh demonstrated, not only that a bar of jelly has a quite respectable tensile strength, if prevented by suitable means from local contraction of section, but that water has an appreciable tensile strength, if the pulling force be properly applied. An experiment, in which Professor Osborne Reynolds supported about 40 in. of mercury in a barometer tube, shows that mercury also has tensile strength. I think, therefore, that it may be absolutely correct to speak of "a pull" on the water.

Mr. Sydney Barnaby (Member): Mr. Taylor asks how cavitation affects efficiency. I think in this way. The screw commences to race as soon as a cavity is formed at the back of the blades, and the waste of power from the increased slip resulting from the racing is much more than can be compensated for by the reduction in surface friction at the back of the blade. If the blade area is made large enough to reduce the total thrust per square inch of projected surface to less than 11¼ lbs., then cavitation is prevented; but I have explained in the paper that it would be necessary, in some cases, in order to effect this to resort either to very wide blades, to a greater number of blades, or to a larger diameter and pitch ratio than would otherwise have been preferable. Mr. Thornycroft has very properly pointed out that the disc, by which I have supposed the screw to be replaced, would only give the same propelling effect if it were abolished after a very short movement and replaced by another in the manner described by Mr. Froude. I knew I was on dangerous ground, but thought I had put myself right by the footnote, which, perhaps, Mr. Thornycroft has not noticed. The footnote states that it would not be true that the propelling effects of the screw and disc were the same if the movement of the disc were continued far beyond the sternpost, but is nearly so if the movement were confined to the length of the screw. In reply to Mr. Wingfield, I believe the temperature to which Mr. Parsons heated the water in his model cavitation experiment was a little below boiling point.

EXPERIMENTS ON THE NATURE OF THE SURFACE RESISTANCE IN PIPES AND ON SHIPS.*

By Professor H. S. Hele-Shaw, LL.D., M.Inst.C.E.

[Read at the International Congress of Naval Architects and Marine Engineers at the Imperial Institute, July 7, 1897; Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

For some time the author has attempted to illustrate to the students of the Engineering Department of University College, Liverpool, by means of lantern apparatus, the actual behaviour of water in flowing through pipes and round the sides of ships, but until recently various contrivances have been adopted with only partial success.

No matter how complex the flow of water may be, unless some foreign substance is introduced, or there are vacuous spaces, there is nothing to indicate what is taking place. Colouring matter may be used at very low velocities, but for the purpose in view, in which reasonably high velocities were required, this is quite useless, as the colour immediately mixes with the body of the water. Foreign substances such as sand and spermaceti were tried, but, apart from the general indistinctness of the stream lines, the sand accumulates in the places where eddies are formed and vitiates the results. The same may be said of most foreign substances. A mixture of disulphide of carbon and petroleum which has nearly the same specific gravity as water, and of course does not mix with it, offered the serious objection of sticking to the surfaces of the glass lantern slide through which it was running and obscuring the light, in addition to being, after several trials, so finely divided as to render the water opaque. It was only by accident that what has turned out to be the most successful arrangement was discovered. One experiment was being made with the section of a pipe with only clear water, when it was found that it showed perfect stream lines upon the screen, and it was then discovered that in the narrow part of the entrance-pipe, where the velocity was greater and of course the pressure less, an induced current of air leaked in, and finely divided bubbles gave exactly what was required on the diagram.

The first point was to determine whether the presence of air vitiated the results, but by experimenting it was found that there was no difference whether the smallest

* Illustrated by lantern apparatus and photograph transparencies.

quantity of air was present, or so large a quantity as to practically render the slide opaque, and it may be said that the general behaviour of the flow of water was practically unaffected by the presence of the air.

It must be remembered that in all these experiments the results are given on a very large scale, the screen being 10 ft. square, and a powerful arc light being used in the lantern. Hence the cross sections of the figures themselves are magnified to a very large scale, and the results can be observed by a close observation of the screen in a way which it is quite impossible to do by looking directly at the actual figure on a small scale, or at its reproduction in a photograph.

One thing appeared evident, as will be shown hereafter, viz., that there were certain important differences between the appearances of flowing water as obtained by these means, and those figures which are, with little variation, given in text-books as representing the behaviour of water flowing past obstructions in pipes, and round bodies moved through the water at rest.

The author happened to show some of these experiments to his friend Dr. Elgar, at Liverpool, who suggested that the results obtained would be interesting as a communication to the Institution of Naval Architects. At the time, the idea was merely to show the effect of stream lines and vortex motion upon ship-shape and other forms and in pipes, but a point which was not understood at first has been specially enlarged upon, as it appears to have an important bearing on the nature of surface resistance.

I may, however, say a word about stream lines. Mr. D. W. Taylor, of the United States Navy, contributed a paper on "Ship-shape Forms," Vol. XXXV., 1894, Transactions of the Institution of Naval Architects, in which he investigated, theoretically, stream lines under conditions almost exactly the same as those which take place in the experimental investigations of the present paper. He supposed the ship-shape forms to have vertical sides and flat bottoms, and to have a sheet of ice at the surface of the water and also at the bottom; if now we replace the sheet of ice by the glass sides in the lantern we have the same conditions as in the present experiments, and it would be interesting to note various points in which the theories set forth by Mr. Taylor are, more or less, confirmed by the experiments. It may also be remarked that, although at first it was a question as to how far the conditions under which the experiments were made, bore a direct relation to the actual conditions of practice, Mr. Taylor considered on theoretical grounds that it would not have a very appreciable effect, except in the matter of wave formation, and the author, in confirmation of this, has found that, when the thickness of the different bodies (that is, the space between the glass) was considerably altered, without altering the cross sections of the immersed bodies or pipes through which water was flowing, no change was made in the character of the flow.

Description of Apparatus.

The experiments to be described divide themselves into three classes—(1) Pipes. (2) Jets. (3) Flow round immersed bodies.

Fig. 1 (Plate XX.) is a diagram showing the general form of lantern slide with which the experiments have been made. It merely consists of a brass frame with an inlet and outlet pipe, each being furnished with cocks so as to regulate the admission and outflow of the water. In the inlet pipe there was inserted at an angle, a small pipe through which the induced current of air could be drawn, and the air-cocks in this regulated the admission of air, which could be shut off altogether when required. A more simple and effective method has been adopted in all the subsequent slides, which is merely to insert a smaller pipe, at right angles, right through the larger main pipe, so as to diminish the area as shown in the figure, having one or more holes drilled in the side of the smaller pipe to admit the current of air thereby induced.

For pipes and channels it is easy enough to give the brass plate any required form, such as is shown in Fig. 2 (Plate XX.). In addition to this, means are taken for admitting separate coloured fluid in the inflowing water for purposes which will be afterwards described, also means by which water of different colour and different kinds of fluid can be admitted to the sides of the pipe.

For the purpose of experimenting upon jets, the frame shown in Fig. 1 is used, the body upon which the water impinges being held in position by small projections fitted into the glass. In this case, the admission of fluid to the skin of the body upon which the jet impinges is arranged for as shown in Fig. 3 (Plate XX.).

For the general case in which a body of water was required to move in parallel lines smoothly across the slide, the special contrivance shown in Fig. 4 (Plate XX.) was devised. This consists, in addition to the main entrance and outlet pipes, of an arrangement of a number of small pipes parallel to each other with a baffle plate opposite to each, fine wire gauze being placed behind the baffle plate. This piece of apparatus proved quite satisfactory in operation, giving parallel stream lines across the whole width of the screen when no obstacle was inserted.

The actual water for the supply of the slides was generally taken from a pipe connected with the town mains; but, in order to insure a uniform flow, a small three-throw pump has been employed, which will be used in the experiments shown in reading the paper. This pump is really a water-meter which has been adapted to suit the end in view.

Further, it has been found necessary, in order to experiment with water under pressure, and particularly for use with the parallel flow apparatus, to have an air

pump and reservoir of compressed air, and by means of this arrangement the air can be admitted even when the water at the smallest part of the pipe is considerably above atmospheric pressure.

A small detail, but one making the greatest difference in the rapidity of effecting changes in the apparatus, is the coupling joint shown in Fig. 5 (Plate XX.), which somewhat resembles the coupling joint of compressed air or vacuum brake, having a ring of elastic packing which acts effectively for laboratory purposes when using water under pressure.

In photographing the effects, a sheet of ground glass is placed between the arc light of the lantern and the water slide, and the photograph obtained directly with an ordinary camera, as suggested by Mr. Robinson (the assistant of the author's colleague, Professor Oliver Lodge).

Result of the Experiments.

Figs. 6 to 23 (Plates XXI. to XXIII.) are selected from a large number of photographs which have been obtained from the actual flow of water. These examples are sufficiently clear without explanation, but it may be noted that the first few are those in which the body is immersed in flowing water, and the differences can be seen in the effect, according as the form is "fair" or otherwise.

In the case of the square-edged body, Figs. 6 and 7, which is turned both sideways and endways to the stream, the water in the latter case appears to be heaped up somewhat in front of the body, so as to form an artificial cut-water, and thus prevent the form of flow which is generally assumed to take place under the circumstances.

Figs. 8 and 9 show the effect of a projection on the side of a body according as the blunt or sharp end faces the current. The egg-shape section in Figs. 10 and 11 shows distinctly the well-known beneficial effect first pointed out by Froude, when the blunt end is used for the bow. Figs. 12 and 13 show what may be taken as a ship, giving the cases of the rudder steady and hard over, and it will be noticed that in the latter case the effect of the body in the current tends to produce a general set round the opposite side of the ship to that to which the rudder is placed; *i.e.*, if the helm is hard aport, the rush of water takes place round the port side of the ship. A circular section is shown in Fig. 14.

The next series of examples, beginning with Fig. 15, show the effect of a jet, Fig. 15 being the action of the jet upon a "fair" form, and can be compared with the action of the jet about the same speed, and under similar circumstances, on a form (Fig. 16) which is not fair; the result being that in the latter case two vortices are produced in front of the obstacle, and two behind it, the difference in appearance of the

vortices formed being caused by the greater quantity of air present before than behind the body. Fig. 17 shows a case in which the velocity is not so great. Fig. 18 is where the velocity is reduced still further—so much so that the whirl or vortex only appears in front of the body, while behind it there is an empty space, as can plainly be seen by the drops on the glass sides. Fig. 19 shows a case in which the velocity is still further reduced, so that now the jet is no longer immersed but free, and falls upon the obstacle running down the sides, and is heaped up in the side and finally escapes underneath. Figs. 20 and 21 represent the effect of the jet upon a flat face in two positions. Fig. 22 gives an example of the flow through pipes in which an obstacle has been placed.

Now in all these examples it will be seen that there is a clear border line round the immersed body, and at that portion of the body which is in contact with the water in the case of the action of the jet, and this is the point which has already been alluded to as being a matter calling for some explanation. In Fig. 23, which will be referred to at greater length later on, it will be noticed that the clear border passes beyond the limits of the body.

The natural question suggested at first was, whether this border is caused by refraction of light in passing through the parallel layers of the glass and water, and very careful means were taken to investigate this point; but, as will appear from what follows, this matter was completely set at rest by subsequent experiments, and need not be alluded to further.

What was, then, the cause of this clear border, which has different breadths at different points, the amount of which can be modified by varying the velocity of flow, which, of course, was quite invisible as long as the air was not admitted, the presence of which the admission of coloured fluid or any finely divided solid bodies in the water did not reveal in any way to the eye?

To obtain an answer to this question the changes effected by rubbing the sides of pipes and obstructions with grease and by roughening the surfaces were first observed, and also the effect of injecting coloured liquid more or less suddenly into the flowing stream. In the latter case it was noticed that the colour seemed to pass first into the general body of the water, and linger last round the portion where the clear border line was shown.

Mr. Okill, my assistant, who has carried out all the experiments with me and constructed most of the apparatus, made the suggestion of admitting coloured liquid at the skin surface itself of the obstruction, and not in the general body of the stream. The way of doing this is shown in Fig. 3.

The wall diagram shows the general effect of injecting coloured fluid into this clear border line, and it will be noticed that the coloured liquid is travelling along in parallel

layers, the deepest colour being nearest the skin of the obstacle. This shows that the rate of motion is slowest at the skin and gradually increases outwards, causing the fluid to be more and more diffused, but it does not directly mix with the darker portion which contains the air. Further experiments showed that, if coloured liquid is injected across the clear border line, it immediately colours the whole darker portion in the slide. Again, air injected into the border, would not remain there, but at once escaped to the outside. Remarkable effects have been obtained by injecting different materials. With the idea of using the materials exuded upon the skin of fishes, but which material is difficult to obtain in quantity, bile was suggested to the author by his friend and colleague, Professor Sherrington, F.R.S., as containing a quantity of the above substance, its function being apparently the lubrication of the intestines. Moreover, bile can be obtained in sufficient quantity from slaughter-houses.

The use of bile for injection at the skin of obstacles resulted in changing the appearance shown in Fig. 17 to that of Fig. 23, the clear border being reduced, and the whole mass of water rendered opaque. For some time the author thought the apparent increase of velocity of flow denoted a reduction of surface resistance, due to the presence of this lubricating material; but special experiments made to test the effect upon the discharge through a pipe by the injection of this substance have, so far, given negative results. Moreover, precisely the same appearance is produced by the use of turpentine as that shown in Fig. 23, and the use of turpentine in experiments with pipes does not give any marked increase in the discharge. These experiments were made by fitting a pipe (4 ft. long), covered with flannel, within another of the same length, so as to form an annular space for the discharge of the water, the inner pipe being filled with the oil—turpentine, bile, or glycerine—which was forced out gradually into the flannel covering as the experiment proceeded. The experimental tank of the college laboratory enabled accurate observations of the rate of discharge under a given head to be made, but further and more complete experiments are required in connection with this matter.

Lantern experiments have been made with sections of pipes, one side being lined with flannel and the other being smooth brass, and the effect of using bile is made evident from a study of its effect upon the rougher side of the pipe. The retardation produced by the flannel can be plainly seen; but, as the bile is injected under the flannel side of the pipe, the velocity of the particles upon that side is at once increased, and the border in which parallel motion of the layers of water is taking place is diminished in width. Again, experiments were made upon a section of circular form which could be turned round and either a rough or smooth surface exposed. With the rough surface (notched with a file) the border was appreciably larger than with a smooth surface, but directly the bile was injected from the skin of this obstacle, the

border was reduced, and the water seemed to glide over the tops of the small projections as if they presented no real obstruction.

Now if the figures giving the effect of jets upon the concave obstacle be examined (Figs. 16—19), it will be seen that they bear out the view that the width of the film decreases with increase of surface velocity, and that, except in the case of the free jet (Fig. 19), the border is most narrow at the point upon which the jet impinges, and gradually increases in width. The case of the free jet is very interesting, as this remains of the *same* width, having the same velocity throughout. In this case it is important to note that the border is not caused by the presence of air, but is merely the effect of refraction upon the curved surface. Again, in the case of the ship's section with the rudder hard over, it will be noticed that the border is very narrow on the side where the flow is accelerated and wider on the other side, and that the line of separation is very much more marked on the former side.

The result of all these observations and experiments has led the author to the conclusion that, the clear border line represents a condition of parallel flow of layers of water past the skin of the obstacle, or the sides of a pipe, in which a state of shearing exists, while outside this, in the darker portion, the water is in a state of sinuous motion, which corresponds to the state of the higher velocity of water.

Members will be aware that the French philosopher Coulomb, more than one hundred years ago, caused a disc suspended by a torsion wire to oscillate in a vessel of liquid, and he thus ascertained that the resistance to various bodies under such circumstances, when the movement is a slow one, varies directly as the velocity of the motion, a fact which is quite contrary to the friction between solid bodies as investigated by General Morin. Colonel Beaufoy, Froude, and others, however, found that, at higher velocities, the resistance varied more nearly as the square of the velocity, and at higher speeds the resistance varied at even higher powers of velocity. The difference of the two conditions in which the variation was directly, or, as the higher power, undoubtedly represented on the one hand the condition of water in which the mere viscosity came into play, resisting the shearing stress of the layers in passing over each other, and on the other hand the breaking up of the water into eddying motion when the resistance was much greater.

Professor Osborne Reynolds investigated the critical velocity at which this occurs, and in his paper on the subject (Phil. Trans., Vol. CLXXIV., Part III., 1883) he gave calculations concerning the critical velocity, accompanied by an account of some beautiful experiments, which showed the sudden breaking up at the critical velocity of the stream in a glass tube, which had been flowing quite steadily until that critical velocity was reached.

Now in this paper he incidentally alludes to the velocity of the water being greatest in the middle of a channel, and zero at the sides. If this is the case, it seems

obvious that in no event can a whole body of water in the tube break up into sinuous motion; for, if the matter be thought out carefully, it is evident that, although it is possible to have one of the conditions by itself—viz., the condition of lower velocity and parallel flow—it is not possible to have the other condition by itself—viz., the condition of sinuous flow—and this leads irresistibly to the conclusion that at some point or other there must be a line of separation between the two.

This, of course, would not be seen in the experiments made by Professor Reynolds, and the diagrams in his paper show the whole body of the water broken up into sinuous motion, which would naturally appear to be the case, from the fact that the colour used would spread through the whole tube when the colour band broke up.

Professor Reynolds expresses his surprise at the suddenness with which the change took place between the two states of flow in the following words :—" I had not therefore considered the disturbances except to try and diminish them as much as possible. I had expected to see the eddies make their appearance as the velocity increased, at first in a slow and feeble manner, indicating that the water was but slightly unstable. And it was a matter of surprise to me to see the sudden force with which the eddies sprang into existence, showing a highly unstable condition to have existed at the time the steady motion broke down."

The author had not read the above paper for many years, and did not, in fact, look it up until after he had arrived at what appears to be the real cause of the clear border-line and of the darker portion; but when the above words were re-read he could not help thinking that, the clearly defined line of demarcation visible in all the experiments, between what must be regarded as the zones of parallel flow and sinuous or eddying flow, was even more surprising and unexpected. In many of the photographs, the line itself is most strongly marked, the presence of air in the water making that line darker than the space beyond, showing in what a sharp and clear-cut manner the change of state occurs; instead of, as one would naturally expect, gradually changing from one state to the other.

To put the matter in a sentence, whereas Professor Reynolds was surprised at the suddenness in *time* at which the change of state took place when the velocity rose beyond a certain point, the foregoing experiments seem to show a suddenness in *position*, where the change of state occurs, which is even more startling.

There are numerous arguments beyond those already adduced in favour of the foregoing way of accounting for the clear border revealed in the lantern experiments. One of the most striking is the extension of this clear border beyond the edge of the immersed body, as shown in Fig. 23, which clearly proves that no optical effect by the body itself can be considered as the cause. Further, the gradual merging at the end

of the clear stream into what has been considered as the portion in sinuous motion does not conflict with the view of a sudden change of state along the boundary of this clear portion, since different layers of the latter must obviously have different velocities.

There is a practical aspect of the whole question upon which the author would only touch with the greatest diffidence. Many inventors have suggested the lubrication of ships by exuding some substance, usually mineral oil; indeed, there have been many advocates of the use of air in this way. The idea in such cases has been to obviate the carrying along of a body of water with the ship. It is clear that neither of these substances can be applied so as to prevent the wetting of the ship's sides, and if once the side of the ship or the inside of a pipe is wet the shearing action at this wetted surface must result, at certain speeds, in setting up eddying or sinuous motion in the surrounding water. This sinuous motion is capable of absorbing all the enormous power taken up by what is known as skin friction without any great mass of water being necessarily carried along bodily by the ship. It may be that, a closer study of the economy of nature in the coverings of fish, water-fowl, and aquatic animals will lead to more successful attempts to reduce the surface resistance in pipes and on ships.

NOTE.—The arrows indicate the direction of flow of the water in all the photographic reproductions.

DISCUSSION.

Mr. F. Elgar, LL.D., F.R.S. (Vice-President): I have been extremely interested, as I am sure everybody else present must have been, in the very beautiful diagrams that have been shown upon the screen, and the instructive and suggestive results they appear to indicate. Our thanks are due to Professor Hele-Shaw for having been good enough to take the trouble to bring up his apparatus and to give us such beautiful illustrations of his experiments. It is interesting to see these, as shown in the printed diagrams at the end of the paper; but the effect is much more striking and real when we see such a clear representation of the water, actually in motion, as we have just witnessed. I do not know what we could now do better than to take time to reflect upon what we have seen with reference to the behaviour of water under the circumstances shown, and the stream lines in which it flows—especially as regards that clear border line, or line of contact with an immersed body, shown so distinctly in all the diagrams, which probably has a great deal to do with surface friction. All who have studied the theory of the subject have had to think and speculate a great deal about the forms of stream lines under various conditions of fluid motion, and often to draw or imagine stream lines for the motion of water past a body immersed or floating in it with very insufficient data, or perhaps none at all, owing to the actual motion of water in the conditions under consideration never having been observed. We have also been accustomed to see in mathematical books diagrams of stream lines and eddies that are supposed to accompany the motion of water past bodies of various

forms, and to account in some way for the nature of the resistances they offer. Although we have thus learnt much in connection with resistance which experience has proved to be correct, we have had to rest content with a great deal that is merely hypothetical. One point illustrated upon the screen to-day was often called attention to by the late Mr. W. Froude. It is that, in driving bodies through the water, it is much more important that they should be fine aft than forward. If the length only admits of a proper degree of fineness at one end, then the bluff end should be forward and the fine end aft. We have seen to-day, by the actual stream lines and eddies upon the screen, some reason why that should be so, and what the effect upon the motion of the water actually is under such circumstances. There is one question I would like to ask Professor Hele-Shaw, and that is, if he could give us particulars of the dimensions of the ship-shape body employed in his experiments, and of the speed of the water that is flowing past it. That would enable us to form some idea of how the speed of the water would correspond with the ordinary speeds of ships. I hope someone may follow me, who has studied this subject, who may have something further to suggest. I do not propose to say anything more, except to thank Professor Hele-Shaw again for his kindness in coming here to-day and showing us the results of his experiments. I had the advantage of seeing some of these in Liverpool several months ago, though they had not then been carried so far as we have seen to-day, and I suggested to him it would be very interesting to the members of this Institution to see what he was doing. He consented to come here and show us the results of his work, and I am sure we are all very much obliged to him.

Sir WILLIAM WHITE, K.C.B., LL.D., Sc.D., F.R.S. (Vice-President): I have been engaged in the other room, and I only saw one or two of the final experiments, but I join in all Dr. Elgar has said as to our indebtedness to Professor Hele-Shaw for showing us such beautiful experiments. For my own part, I propose to read his paper with the greatest care. It seems to me that the experiments are extremely suggestive as to some changes which might be made with advantage in details with a view to diminished resistance.

Mr. D. W. TAYLOR (Member): Sir Nathaniel Barnaby, Ladies and Gentlemen, as author of some theoretical work on stream lines, kindly referred to by the author of this paper, I should like to contribute a very few words to the discussion. I think the members of this Institution are to be congratulated on Professor Hele-Shaw laying before us this interesting paper, and showing us such beautiful experiments. It throws much light on a subject concerning which we have had hitherto very little knowledge. I think we may conclude from what we have seen to-day that we shall soon know much more about it than we have ever known before. With reference to the author's remarks as to stream lines, on page 146, we have sometimes a very unpleasant surprise when our theoretical work is put to the test of practical experiment, especially when the experiments are made by other people, and it gives me pleasure to see the statement that my theoretical conclusions are borne out fairly well by the author's experiments. Professor Hele-Shaw has very modestly said but little as to the practical application, or value, of what he has shown us, but we see he has made some experiments in a practical direction, and it is to be hoped that they will be continued. With regard to what Professor Hele-Shaw says as to a closer study of the economy of Nature in the coverings of fish, &c., I hope we may look forward to the day when the ingenuity of man will give us results more or less approaching nature. Professor Hele-Shaw states on page 153 that "many inventors have suggested the lubrication of ships by exuding some substance, usually mineral oil; indeed, there have been many advocates of the use of air in this way." I wish to confirm that statement most feelingly. Many times have inventors proposed various projects of the sort to our Navy Department, and it has

often fallen to my lot to try to convince such an inventor that his ideas were impracticable; I have not succeeded in convincing a single inventor yet, but I hope that, with the aid of the information made available by this paper, I shall have more success in the future.

Sir EDWARD REED, K.C.B., F.R.S. (Vice-President): Mr. Chairman, Ladies and Gentlemen, the invitation to speak here is a very difficult one to accept, because the acoustic properties of the hall are so bad that, sitting even a little distance from the platform, it is impossible to hear a sound. I should like to bear my testimony to the value of these experiments, and to their suggestiveness. The initial exhibition we have had confirms very strongly, and illustrates, several well-known facts. For instance, I think Beaufoy showed by actual experiments that, with a certain velocity, the resistance to a triangular body towed base first was less than if you towed it with the angle first, and the reason for that was very prettily illustrated by the first experiment. I remember in the Black Sea, in Sebastopol Harbour, I had the opportunity of steaming up and down the harbour in one of the circular ironclads, a ship entirely circular. When the vessel was going at her full speed, which was not a very high one, it was curious, looking over the bow, to observe that, where one might hastily have expected great pressure, there was no pressure at all. For a considerable distance across the bow, the covers of pipes were flapping to and fro with perfect indifference, as if there were some little disturbance going on, but not a disturbance sufficient to close them, and keep them closed. Further, one saw quite large weeds reaching out forward from the vessel. The inference I drew from it was that, if you force a body of an ungainly shape through water, the water accommodates itself to it, and forms a sort of water bow for itself, and perhaps even that has an advantage. But the stream lines vary. I should not have risen at all, except for the purpose of saying that it seems to me that it is necessary, in order to fully appreciate and put a proper value upon these experiments, to know a little more about them than, at any rate, I succeeded in hearing. Whether the author has more in his paper I do not know, but I think the phenomena would be very different at different velocities, and one would be greatly interested in seeing to what extent and in what manner the phenomena were changed by increases and decreases of velocity. I am sorry that I can say nothing more than that I admire the experiments showing the effect of ejected substances upon the surface of the water, and anticipate many consequences in the future from them. I can only follow the example of Sir Wm. White, and say, if I may, that I shall very carefully study this paper, which strikes me as being one likely to be very fruitful indeed in the future. As an old member, I am very grateful to Dr. Elgar for getting Professor Hele-Shaw to come here, and all the members of the Institution are deeply indebted to Professor Hele-Shaw for the trouble he has taken, and the time he has given us.

Professor H. S. HELE-SHAW: Dr. Elgar has made an inquiry with regard to the speed of the water in the experiments, and the same point has been touched upon by Sir Edward Reed. As a matter of fact the speed varied considerably, and at different times may have ranged from 10 ft. or 12 ft. per second down to 2 ft. per second. The experiments, however, are of the character of an introductory series, and it is impossible to do more, on the present occasion, than show a certain number of diagrams and slides, and to draw some conclusions as to the nature of the border line between the two states of motion in water, which, as far as I am aware, has not been made visible before. The remarks of Mr. Taylor, of course, are extremely interesting, and he has raised a point which must strike everybody as to the nature of the skin of a fish. I thought that I had only to go to my colleague Professor Herdman, a Fellow of the Royal Society, and a great authority on fish, about the subject and obtain all the information I required. He could tell me very little, at any rate about the mechanical properties of the skin of fishes. I have since made some experiments myself on the

subject. I first got some eels, and, having skinned them, I stretched their skins on a pipe which, inserted in a larger pipe, formed an annulus. Upon measuring the flow by means of our experimental tank, far from improving the flow above that taking place with a metal pipe of the same size, the dead eel skin seemed to retard the flow, and seemed to present more resistance, giving about the same resistance as when I covered the pipe with flannel. The diminished resistance only occurs when the skin is exuding the necessary material secreted when alive, that is, if it be assumed that the resistance *is* less in the case of fishes than artificial bodies. I have taken a trout out of an aquarium and proceeded to apply dry blotting paper to its skin. The skin seemed not to wet the blotting paper to any appreciable extent, and gave quite a different result to that obtained from dipping one's hand in the water. I have also experimented with the skin of a skate, apparently a very slippery surface, which I put on one side of a curved piece of wood. The skin of the fish seemed to present as much obstruction to the water as the wood itself. I only mention this fact to show that there is a great deal to be learned yet concerning the surface resistance of bodies, and I remark that a fish does not produce the phosphorescence that the ship does, unless it jumps out of the water and so breaks the surface. There must, at any rate, be some difference between what the fish is covered with and what we cover our ships with. With regard to the pressure at different points, this is no doubt varying all round the surface of an immersed body against which a stream is impinging. I had a circular body made so that it could be turned round in the lantern. I then had a sort of gauge fitted to it, and I found the pressure varied from the front, where it was much above the atmosphere, to a certain point where it was equal, beyond which a vacuum was formed. No doubt that experiment has been made before. I noticed that, wherever the pressure was high, the clear film indicated in the photographs was narrow, therefore there was some connection between the thickness of the film and the pressure. In conclusion, perhaps you will allow me to express my thanks to the meeting, and to the gentlemen who have spoken, for the very kind and encouraging way in which they have received my paper. Especially I wish to thank Sir William White, Sir Edward Reed, and other gentlemen of great practical experience who have intimated that it will be worth while to pursue these experiments and obtain further facts. I also wish to thank one of my students, Mr. W. H. Riddlesworth, B.Sc., for the valuable assistance he has given me on the present occasion.

The CHAIRMAN (Sir Nathaniel Barnaby, K.C.B., Vice-President): Ladies and Gentlemen, we have arrived at the close of our official proceedings. I have to inform you that there will be no formal votes of thanks; that I give to Professor Hele-Shaw, in your name and my own, our very hearty thanks. I may also say to our foreign guests present how much pleasure their presence has given us. We shall now enter upon a different part of our programme in another place.

SPEECHES FOLLOWING THE DINNER

GIVEN AT THE KING'S HALL, HOLBORN RESTAURANT, ON WEDNESDAY, JULY 7,
BY THE INSTITUTION OF NAVAL ARCHITECTS,
IN HONOUR OF THE FOREIGN REPRESENTATIVES AT THE CONGRESS.

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): My Lords and Gentlemen: I give you the toast of "The Queen." So much has been said within the last few weeks concerning our beloved and revered Sovereign, so much well-merited praise has been bestowed upon her, that, in attempting to do justice to Her Majesty's private virtues, and to her great public capacity, we run a risk of repeating a tale already a thousand times told. The wisdom with which she has wielded the Royal power during all these years has broadened and strengthened the foundations upon which this power rests, while she has maintained the true dignity of her throne, the real influence of her crown. She has demonstrated to the world the possibility of combining the widest constitutional liberty with a monarchy almost as ancient as the history of the country over which she rules. She has solved one of the most difficult problems of the age—the combination in one form of government of perfect political freedom with the highest idea of Imperialism. Her Majesty's name is revered and respected from end to end of the civilised world. She commands the devoted loyalty and personal affection of her people of all races and creeds. She has shown an example to those who will some day succeed her, and to each and every one of her subjects the example of a patient continuance in well-doing, and of never relaxing for one moment during a long and eventful life her determination to do her duty. (Loud cheers.)

The PRESIDENT (the Right Hon. the Earl of Hopetoun, G.C.M.G.): My Lords and Gentlemen, the next toast I have to propose to you is that of "The Prince and Princess of Wales and the Rest of the Royal Family." None of Her Majesty's subjects works harder than the Prince of Wales, at this time more especially, and we take it most gratefully that His Royal Highness should have found time to give us his patronage as Honorary President of the Congress. The Princess of Wales is the gentlest, the most beloved, and most beautiful lady in the land; and with the health of the Royal couple I give you also that of the other members of the Royal Family, who so admirably adorn the high position to which Providence has been pleased to call them.

The Right Hon. G. J. GOSCHEN, M.P., First Lord of the Admiralty: My Lords and Gentlemen, I rise to propose a toast which I know will be drunk with great enthusiasm. I propose what I may call the toast of the evening, "Our Guests"; those who have come from all parts of the world to take part in this interesting gathering; those who may, perhaps, be our rivals in inventive genius, but are our friends at this table and in the assemblies which we are holding. I see before me a unique gathering. Men of genius in many a direction of scientific and practical inquiry have come, not only

from all parts of the world, they have come from every department of scientific knowledge: the men who invent the defence, the armour-plates which are to receive the attack; the men who devise the guns that are to defeat that defence. They are all amongst us: constructors of ships, constructors of machinery, artillerists, metallurgists, chemists, marine engineers, and I do not believe that, on many occasions, so great a brain power has been brought together as is gathered in this room to-night. It is sometimes thought that this Institution of Naval Architects refers to what we in England call Naval architecture alone, but that is not so. It embraces in its ranks all classes of shipbuilding, all classes of marine engineering, and I do not know whether, beyond the circle of those who are gathered here together, it is sufficiently known what genius is required, what study is necessary for those productions of which the public enjoy the advantage. We have here the men who, in their solitary study, work out those scientific theories which are invaluable to the naval architect and to the naval engineer. We have amongst us the men who invent and think, the men who apply, and the men who use the appliances. We have the scientific men who work out all those theories which entirely baffle the intellectual aspirations of inferior men; we have amongst us the men who understand them. But, invaluable to the theorists, we have also here the men who apply those theories in practice. Gentlemen, we greet amongst us distinguished admirals who sail in the ships which have been devised, and we have distinguished naval engineers who apply those principles of propulsion which have been invented by the mechanical engineers. There are amongst us to-night constructors, engineers, admirals, artillerists, chemists—men of science of every rank and of every degree of capacity, and not only that, but we have in this assembly men who have inherited from their fathers engineering skill, men who conduct firms which have been founded by their grandfathers, but who, progressing with the spirit of the age, from year to year, have developed mechanical and engineering science and kept up the hereditary principle of genius. On the other hand, we have men amongst us who, beginning in the workshop, have risen on the wings of genius to the highest rank of fame in ship constructing and engineering work. Your science knows no differences of rank, and the youngest apprentice who begins in the workshop may come to be the constructor of gigantic navies, honoured by Governments, honoured by the public whom he serves. Those members of this Institution who have taken a principal part in the construction of ships belong to two classes: those who have developed the mercantile ship, and those who have developed the man-of-war. Both have been equal in their endeavours to arrive at perfection, the one at the perfection of destructive power, the other at the perfection of mercantile use. Gentlemen, if one thinks what has been done during the last forty years, the mind stands almost aghast at the progress which has been made, and humanity must be thankful, in many ways, for those inventions, for those scientific appliances, and for those intellectual efforts which have brought about the present position. I have been told that forty years ago every single unit of horse-power required 5 lbs. of coal to develop it. It has now been reduced to about 1¼ lbs. of coal per horse-power. What does that mean? It means not only economy to the shipowner, or to the Government, but it means a cheapening of the methods of conveyance by the economy in coal; thus freights are reduced, and the products of the different parts of the world are brought to other countries with greater speed, with greater economy, and consequently with greater advantage to the public at large. And though it may seem a somewhat indirect or distant process, the theorists, who in their study have developed the dynamical theory of heat, have contributed, each in their way, to the cheapening of commodities and of food to the people at large. Gentlemen, what have you not done for the public? You have quickened passages, you have diminished distances, you have brought countries more and more into close community. We have here amongst us men representing every form of science. We have the electricians—what have

they not done for us? I will not say that they have contributed to light up this hall; they light up the ships, thus contributing, as every admiral will know, much comfort to the crews who sail in them. So with the chemists and metallurgists who have dealt with the properties of material, and who have told you how steel can be substituted for iron, and how space can be saved—all these have contributed to the possibility of bridging over the ocean by quicker methods and safer methods, and in a manner more conducive to the comfort of those who cross the seas. Gentlemen, I must not detain you by speaking of the different directions in which scientific principles have been applied. How some distinguished men have redistributed the *rôles* of fire and water and established boilers under a system of limited liability. I must not pause to consider how those mighty changes have taken place. There are amongst us here to-night inventors of genius, and I hope they have all had their reward. I hope that the enthusiasts have not been damped in their aspirations; I hope, also, that the inventors will have mercy upon the administrators and not push them too hard. I remember, Gentlemen, that when I held the post which I now hold some three and twenty or four and twenty years ago, we had to deal with new constructions. It was in the days of the ships devised by Admiral Popoff in Russia, and there was a famous ship called the *Devastation* designed here in England. It has had a most successful career, but it was a ship which caused my hair to grow grey prematurely, before its time, because half the naval world told me that, if I sent that ship to sea, I should be guilty of murder, while the other half declared that, if I did not send her to sea, I should sacrifice the maritime supremacy of my country. She went to sea and our supremacy was not sacrificed, but I was an older man from that time. Gentlemen, there are many men here—some sitting very near me—who know what it is to have to decide whether inventions shall be accepted or not. You, gentleman, have done wonders. I see, as I have said, before me here brain power of the highest description. What have you not accomplished? You have beaten down Father Time and made him subservient to your wishes. You have shortened distances in the voyages across the Atlantic in a manner which our fathers would have thought marvellous. You have bound electricity to your service; you have made captives of fire and steam, and I do not know in what you have not had success. Now, what is wanting to your triumph? One thing you have not accomplished. You have been beaten in one respect, and I submit it to the competitive genius of an assembly such as this. You have achieved all these wonders, but there is one physical difficulty which you have never yet overcome. You have fought time; you have fought distance; you have fought fire; you have fought water; but one miserable, contemptible physical weakness you, with all your genius, have never been able to overcome: you have not been able to get over the trouble of sea sickness. You have devised the most beautiful lines, bilge keels, and every possible appliance of science, but you have been beaten hollow by the *mal de mer*.

Messieurs, ce mot Français me rappelle que peut-être parmi nos amis ce soir il y a des personnes qui ne comprennent pas l'Anglais suffisamment pour pouvoir suivre mon discours. Je me lance, donc, pour quelques instants dans cette langue si délicate qui tend des pièges si dangereuses aux étrangers intrépides qui l'abordent. Or j'ose espérer que la chaleur de mes sentiments obtiendra pour moi l'indulgence de ceux qui m'écoutent si je commets des pêchés contre les règles absolues du despotisme implacable de la grammaire. Messieurs, au nom de l'Institut je vous salue comme amis et confrères. J'espère que, quand vous retournerez chez vous, vous emporterez avec vous les meilleurs souvenirs, non seulement des conférences scientifiques et techniques auxquelles vous avez assisté, mais aussi des occasions moins serieuses où il y a eu plus d'hilarité et où nous avons diné et causé ensemble et lié, je l'espère bien, des liens d'amitié.

(The Right Hon. Gentleman then addressed a few words to the German guests in their own language.)

Gentlemen, I ask you to drink with enthusiasm the toast of "The Guests of the Institution of Naval Architects," our brothers in science—if I may say so, not being a scientific man myself—brothers in science who have honoured us with their presence in this country, and of whom we hope that they will carry back each to his own country the memory of a pleasant sojourn, and to whom we offer the most cordial welcome. (Prolonged applause.) I wish to couple with this toast the name of Admiral Bendemann of the Imperial German Navy, of General Hyde of the United States of America, and of Mons. Normand, Vice-President of the Association Technique Maritime of France.

Rear-Admiral BENDEMANN: My Lord and Gentlemen, it is a great honour and a very great pleasure that I have to fulfil in replying to the First Lord of the Admiralty, and in thanking him for the most eloquent and cordial words that he has had the kindness to address to us. I would intrude upon you, if I tried to say more than a few words after the most admirable speech which we have just listened to. You will allow me, therefore, only to express the thanks of the guests—I am sure I may say of all the guests, but most certainly of my own countrymen—to the President and members of the Institution of Naval Architects, not only for the most interesting and highly instructive papers and speeches which we heard in the course of this day and yesterday, but principally for the most cordial reception and truly British hospitality which we find here to-day and wherever we meet. It is not the first time that I make this most agreeable experience, and I am quite sure that a great many of my countrymen who are here this evening are in the same position: I mean the experience of this very warm and refined British hospitality. May I conclude by repeating a few words which I had the honour of transmitting to my Lord, the President, a few days ago. His Majesty the Emperor, when he dismissed me in Kiel a few days ago, was pleased to command me expressly to remember him to the President, the Council, and the members of this Institution. I wish once more to give my hearty and most sincerely felt thanks to the First Lord for his kind words, and to the President and members of this great British Institution for the kind and cordial reception that we have found here in England.

General HYDE: My Lords and Gentlemen, the only regret I have on this happy occasion is that the President of our Society, Mr. C. A. Griscom, is unavoidably absent. He could have answered to this toast for the United States much more worthily. Your welcome to us, your kind hospitality to us, will long linger in our memories. Our hearts were already warm toward the Mother Country. We have seen a great many things over here; we have seen a great many interesting things; and, perhaps, the most interesting thing to me is to see how the great heart of Britain goes out to her Navy and to her Mercantile Marine. We have seen how the will of a great nation, expressed to members of your Society, has produced your magnificent fleet, which, by a seeming paradox, may be a promoter of peace, though destined for an engine of war. We all know that meetings like these are helping to bring about the day when there shall be perpetual peace and goodwill among men. I do not know whether I might be pardoned in this Hall for telling a story:—Once a New York sportsman went to the wilds of Maine, after moose and caribou. When many miles beyond any human habitation, he met an old trapper, who accosted him: "Stranger, where might you be from?" "I came from New York," said he. The trapper answered: "Stranger, how can you bear to live so far away!" Now, the only trouble with you Englishmen is that you live so far away! I do not doubt that the labours of men I see here present will yet bring us, at least, a day nearer together. Gentlemen, in behalf of your kindred American Society, I thank you.

Monsieur J. A. NORMAND: My Lord and Gentlemen, in the absence of M. de Bussy, the venerable President of the Association Technique Maritime, I wish to express to you the thanks of all the members of our Institution for the many kindnesses bestowed upon us during the Congress. I thank you especially for having had sufficient confidence in our friendly feelings to invite us to take part in your rejoicings, during that ever to be remembered year of the national Jubilee. You may be assured that none amongst the strangers present joined more heartily than we Frenchmen did in your beautiful anthem, "God Save the Queen."

Vice-Admiral DUPERRÉ spoke in French; his speech was translated by Mons. De Pulligny as follows: Gentlemen, I desire to propose the health of the President, the Members and Associates of the Institution of Naval Architects. I am sure that I am expressing the feelings of all your foreign guests in thanking you warmly for the very kind welcome which you have given to them. All the members of the Congress are most grateful for the welcome that has been shown during the last two days. I am happy to congratulate the Institution on all it has done in the past, on all it is doing and on all it will do for the progress of maritime science. I should have liked to have had the Right Honourable Mr. Goschen near me, in order to congratulate him on the admirable spectacle of maritime power that the late review at Spithead has given to you. Yesterday His Royal Highness the Prince of Wales, in opening your meetings, offered his welcome. We are all most grateful to him for having done so. In receiving the members of this Congress at Windsor Her Majesty the Queen gave us an opportunity of offering our humble and sincere congratulations in addition to all those which have been offered to her from every part of England and from the hearts of all her loyal subjects. Once more, Gentlemen, please to accept our heartfelt thanks, and allow us to propose the health of the President and members of your Institution.

The Right Hon. the Earl of HOPETOUN, G.C.M.G. (President): M. l'Amiral Duperré, my Lords and Gentlemen, I have to thank you most cordially on behalf of the Institution of Naval Architects for the kind way in which you have received and drunk this toast. I can only wish, and I say this in all sincerity, that a more finished and capable speaker could have been put up at this juncture—one who could have done greater justice than I can, not only to the complimentary words of the gallant Admiral, but also to the importance of the subject with which he has dealt. But, however much I may distrust my capacity to speak in adequate terms of the Society which I represent, I can cordially agree with the speech of the gallant Admiral, and I make so bold as to say that, among the many kindred bodies which exist in this country, none have done, or are doing, greater service to the cause of science and civilisation than is our Institution. I use the word civilisation advisedly, because it is impossible to conceive a more powerful engine of civilisation than the facilitating of means of communication between the different parts of the world. Many of the greatest theoretical advances, most of the great practical improvements in the science of shipbuilding and marine engineering have been announced to the world from the platform of this Institution; they have been freely and fully discussed by our members, and their adoption thereby greatly facilitated. I venture to repeat, what I have already stated, that these advances and improvements are not peculiar to—they do not belong to any one nation. It is our proud boast that we tender the warmest welcome to workers of all nations, and that we derive the greatest benefit from the co-operation and support of our neighbours on all sides. I pass, gentlemen, from the work which has been done in the past. I believe that we have just cause to be proud of the work which we are doing in the present. The Institution of Naval Architects is the parent of this great International Congress which we are holding at the present time. We may be forgiven if we are proud of our offspring. It is a healthy

and wholesome child, and our only regret is that its life must be compressed into so short a space. Its career can only be measured by days, but during that short space we believe—and we are not too sanguine in so believing—that much good work will be done. The foundation of much that is useful in the future will be laid. Ethnological reasons, difference of customs and language, diversity of religions, have rendered it necessary and natural that the peoples of the world should divide themselves up into States and Countries. Each nation is wisely and properly jealous of its own interests. It sometimes comes to pass even that the interests of one community may run counter to those of its neighbours; but science knows no such artificial barriers and boundaries; it is cosmopolitan, and belongs equally to all nations. When we meet together, as we are doing at present, we forget, for the time being, that we are subjects and citizens of different States. We are here for one great purpose, and to do homage to one great mistress—Applied Science—a mistress who commands our respect as well as our affection, and the worship of whose charms can never become tedious to us. And apart, too, from the purely scientific aspect of such a Congress as this, may we not hope that the presence of so many distinguished individuals of both sexes, from different parts of the world, may tend in some small degree to improve and strengthen the good relations which already exist between their various countries? May we not hope that our guests may go away with better impressions, a truer understanding of us than they have ever had in the past? One cannot help hoping that they may perchance say to their friends, when they get home, "Really, these islanders are not such bad fellows, after all. Of course, they are mightily keen in business matters, and look well after their own interests; but when you get them away from the shop they are not otherwise than pleasant folks. We have always understood that they were rather a sombre people, taking their pleasures sadly; but when you see them as we saw them, in gala dress, chiefly composed of Union Jacks and other national flags, they really are quite a cheerful and interesting people." And we, too, here, who belong to this island, we may learn many a lesson, and do ourselves no little good, by our contact with our courteous and delightful guests. We can learn the lesson of single-minded patriotism, the will to make great sacrifices for the public good, the power to endure heavy burdens for the sake of our country. If this Congress should tend, in ever so small a degree, in such a direction as the one which I have indicated, it will have justified its existence, and the present Institution may be congratulated on having given birth to it. I thank the gallant and distinguished Admiral who proposed this toast for coupling my name with that of the Institution of Naval Architects. I confess that, at times, I am lost in wonderment and amazement how it comes to pass that I, a very ordinary individual, should find myself honourably associated with so distinguished a body of men, and I have ventured on several occasions to tell you quite frankly my exact views concerning ships. I speak with all the weight and authority of the position which I occupy when I say, that I strongly object to ships being put to an improper use. I cannot imagine a more improper use to put them to than by employing them to take the President of this Institution to sea in rough weather. I esteem and respect my colleagues whom I see around me, and I admire the talented gentlemen who are our guests. I object, therefore, very strongly to putting them to an improper use by submitting them to the boredom of sitting here and listening to a long speech from me at this somewhat advanced hour of the evening, so I will conclude by seizing the opportunity of expressing to our distinguished foreign friends the sincere gratification which is given me personally to see them here in London along with the ladies of their party, to whom I offer my homage. I would assure them that it is my earnest desire, and that of my colleagues, to promote their convenience and comfort to the best of our power as long as they are with us, and I would again thank them for the more than handsome manner in which they have drunk the health of the Institution.

NOMINAL INDEX.

BEING AN ALPHABETICAL LIST OF THE NAMES OF THE AUTHORS OF PAPERS READ BEFORE THE INSTITUTION, AND OF THE SPEAKERS WHO TOOK PART IN THE DISCUSSIONS WHICH FOLLOWED THE READING OF THE PAPERS.

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Barnaby, Sydney W. ...	*On the Formation of Cavities in water by Screw Propellers at high speeds*	139
	Reply to the discussion on the above paper	144
Bendemann, Rear-Admiral	Replying to the toast of "The Guests" at the Congress ...	160
Bertin, E.	*Hardened Plates and broken Projectiles*	1
	Explanation as to the tables of experiments in his paper ...	22
	Reply to the discussion on the above paper	24
	Nature of the spiral waves produced by impact of projectiles on armour	24
Biles, Professor J. H. ...	Uses of non-flammable wood	32
	Adaptability of non-flammable wood to the decks of ships ...	33
	Inviting members to witness experiments with non-flammable wood	34
	Congratulating Sir Edward Reed on the manner in which he prepared his paper	99
	The mathematical theory of the strength o ships ...	99
Boys, Admiral H. ...	Non-flammable natural wood in New Zealand	30
Bredsdorf, J.	Appliance used in ice-breaking at Flensburg Harbour ...	114
Brown, Andrew ...	The ferry steamer *Finnieston* on the Clyde	114
Chairman (Sir Nathaniel Barnaby, K.C.B.)	Thanking Mr. Manuel for his paper, "Crank and other Shafts used in the Mercantile Marine"	138
	Thanking Professor Hele-Shaw for his paper on "Experiments on the Nature of the surface Resistance in Pipes and on Ships"	156
Chairman (Sir Edward Reed, K.C.B., F.R.S.) (*See also Reed, Sir Edward*)	The discussion on Sir John Durston's and Mr. Milton's paper	52
	Thanking Sir John Durston and Mr. Milton for their paper "A Review of the History and Progress of Marine Engineering in the Royal Navy and Mercantile Marine, from the Foundation of the Institution of Naval Architects to the present Date"	57

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Chairman (Sir Edward Reed, K.C.B., F.R.S.)	Thanking M. Sigaudy for his paper on "Water-tube Boilers in high-speed Ocean Steamers"	64
Chairman (Sir William White, K.C.B., LL.D., Sc.D., F.R.S.) (*See also White, Sir William*)	Thanking Sir Edward Reed for his paper on "The Advances made in the mathematical Theory of Naval Architecture during the Existence of the Institution"	104
	The discussion on Captain Tuxen's paper	112
	Thanking Captain Tuxen for his paper, "Danish Railway Ferries and Ice-breaking Steamers"	115
	Willingness of Shipbuilders to place their information and experience at the disposal of the profession	119
	Thanking Mr. Johnson for his paper on "Graphic Aid in approximating Hull Weights"	120
Courtier-Dutton, W. T. ...	The difficulties of calculating the strains on ships	103
	The strains on ships caused by sending them to sea in ballast	103
	The double bottoms of American lake steamers	103
Daymard, V.	Thanking Sir Edward Reed for his paper	100
Denny, Archibald	His firm formerly taunted with being too scientific ...	99
	Congratulating Sir Edward Reed on the manner in which he prepared his paper	99
Donaldson, John ...	Early use of Belleville boilers in the French Navy ...	57
	The application of high pressure steam to marine propulsion by Mr. Thornycroft	57
	Experiments with oil fuel	57
Duperré, Vice-Admiral ...	Proposing the toast of "The Institution of Naval Architects"	161
Durston, Sir John, K.C.B., R.N.	*A Review of the History and Progress of Marine Engineering in the Royal Navy and Mercantile Marine, from the Foundation of the Institution of Naval Architects to the present Date*	35
	The advantages of twin screws	129
	Experience with hollow shafts in the Navy	129
Elgar, F., LL.D., F.R.S. ...	The diffusion of scientific knowledge amongst engineers and shipbuilders	97
	Examples of the ignorance formerly prevailing amongst ship designers	98
	The work done by the Institution in diffusing scientific knowledge in the profession	98
	Professor Hele-Shaw's experiments on the nature of surface resistance	153
Ellis, Charles	Increased resistance of armour due to Harveying ...	22
	Comparative resistance of thick and thin Harveyed armour ...	22
	Recent improvements in armour due to Herr Krupp ...	22
	Non-flammable Wood	26
	Reply to the discussion on the above paper	33
	The strength of non-flammable wood	33
	The weight of non-flammable wood	33

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Ellis, Charles	The cost of non-flammable wood	34
Goschen, The Right Hon. George J., M.P., First Lord of the Admiralty	Address of welcome to the Congress	li
	Proposing the toast of "The Guests" at the Congress... ...	157
Haswell, Charles H. ...	Promises to give his reminiscences of steam navigation in the United States	55
Hele-Shaw, Professor H. S., LL.D.	*Experiments on the Nature of surface Resistance in Pipes and on Ships*	145
	Reply to the discussion on the above paper	155
	Experiments on the surface resistance of fish skins ...	155
Hills, Arnold	Behaviour of non-flammable wood when subjected to intense heat	32
	Weight and cost of non-flammable wood	32
Holt, Alfred	Effect of partly immersed propellers on the life of shafts ...	134
	The advantages of making screw propellers as small as is consistent with efficiency	134
Hyde, General	Replying to the toast of "The Guests" at the Congress ...	160
Johnson, J.	*On graphic Aid in approximating Hull Weights* ...	116
	Reply to the discussion on the above paper	119
Manuel, G. W.	*Crank and other Shafts used in the Mercantile Marine* ...	121
	Reply to the discussion on the above paper	136
	Advantages of solid as compared with hollow shafts ...	136
	Forged scrap steel shafts	137
	The life of shafts in the cargo steamers of the P. & O. Company	137
	Advantages of keeping the dimensions of screw propellers as small as possible	137
	Advantages of lignum-vitæ bearings for shafts	137
	The effect of corrosion on the life of shafts	138
Martell, B.	Approximate methods of calculating hull Weights	119
McFarland, W. M.... ...	The preservation of marine boilers	56
	The simplification of the marine engine	56
	The use of the hollow shafts in the U.S. Navy	130
Milton, J. T.	*A Review of the History and Progress of Marine Engineering in the Royal Navy and Mercantile Marine from the Foundation of the Institution to the present Date*	35
	Value of built crank shafts	130
	The causes of failure of screw shafts in tramp steamers ...	130
	Method of making shafts from scrap iron	131
	Value of forged scrap steel shafts	131
	Tensile strength of steel used for crank and propeller shafts	131
	Difference in the behaviour of iron and steel when cracked ...	131
	Nickel steel for shafts...	131
	Effect of corrosion at the junction of the liner and the steel on the life of propeller shafts	132
	Effect of bending strains on the life of shafts	132

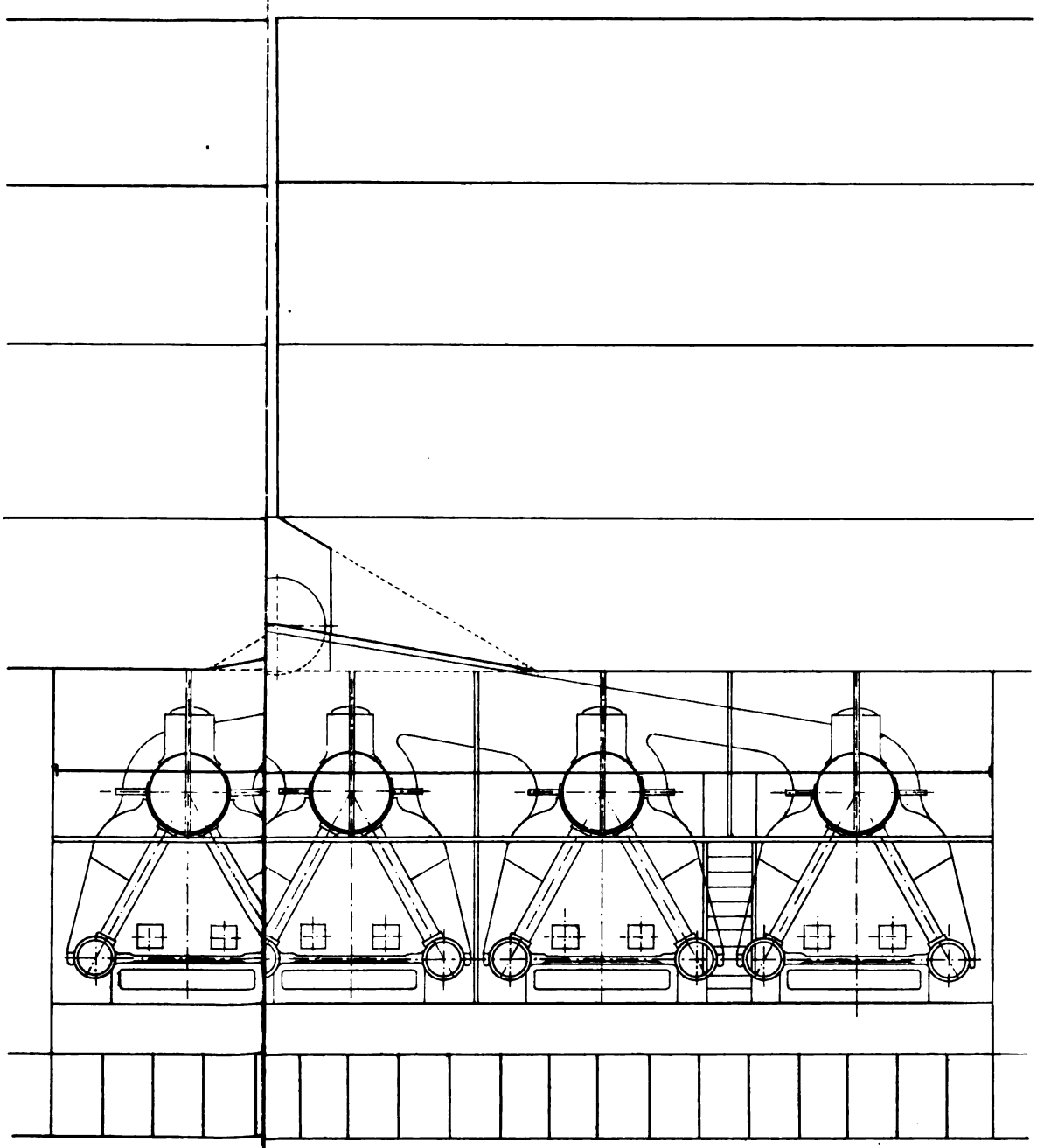
Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Milton, J. T.	Evil effect of running steamers in ballast on the life of their cranks	133
Mudd, Thomas... ...	Method of preventing the corrosion of tail shafts	135
Nielsen, Captain K., R.D.N....	Use of ice-breaking steamers in the Baltic	113
Normand, J. A. ...	The improvements in marine engineering introduced by the late Mr. Benjamin Normand	52
	Replying to the toast of the guests at the Congress	161
Oldham, J. R.	The weight of non-flammable wood	34
	The strains in ships caused by docking	103
	The practice of docking ships in the United States ...	103
	The double bottoms of American lake steamers	104
President, The (Right Hon. the Earl of Hopetoun, G.C.M.G.)	Inaugural address at the International Congress... ...	lii
	Welcoming the foreign guests	iii
	Congratulating the Queen on her Diamond Jubilee ...	liii
	Comparison between British trade in the years 1837 and 1897	liv
	Progress of naval architecture and marine engineering during the Queen's reign	liv
	Comparison between the *Great Western* and the *Lucania* ...	liv
	The *Great Britain*	liv
	The *Great Eastern*	lv
	Congratulating Sir John Durston on being made a K.C.B....	lv
	The state of the Navy in 1837	lv
	Development of the Navy during the Queen's reign ...	lvi
	French and American improvements in shipbuilding and marine engineering	lvii
	Telegram of congratulation to the Queen	lvii
	Thanking M. Bertin for his paper on "Hardened Plates and broken Projectiles"	25
	Thanking Mr. Ellis for his paper on "Non-flammable Wood"	34
	Proposing the toast of H.M. the Queen	157
	Proposing the toast of the Prince and Princess of Wales and the Royal Family	157
	Replying to the toast of the Institution	161
Reed, Sir Edward J., K.C.B., F.R.S.	*On the Advances made in the mathematical Theory of Naval Architecture during the Existence of the Institution* ...	67
(*See also Chairman*)	Reply to the discussion on the above paper	104
	The resistance to motion of circular ironclads	155
	Professor Hele-Shaw's experiments in the nature of surface resistance	155
Robinson, Leslie S.... ...	Water-tube boilers in ocean steamers	64
Scott, John, C.B., F.R.S.E.	The possibility of using water-tube boilers in the Mercantile Marine	62
Seaton, A. E.	Influence of the Royal School of Naval Architecture on the progress of marine engineering	53

Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Seaton, A. E.	The services of the late Mr. Richard Sennett to marine engineering in the Navy	53
	Congratulating Sir John Durston on being made a K.C.B....	53
	Design of a torpedo catcher in 1872 by Sir Edward Reed ...	53
	Early use of the surface condenser and distiller by Samuel Hall	54
	First introduction of water-tube boilers in marine propulsion	54
	Use of high pressure steam by Loftus Perkins	54
	Use of oil fuel will be retarded by difficulties as to its price	54
	Use of oil fuel in a torpedo-boat by Messrs. Doxford	55
	The *Turbinia*	55
	The invention of the steam steering gear by Mr. Macfarlane Gray	55
	Importance of properly designing the main frame-work and bearings of marine engines	134
	Mild steel shafts will not run on gun-metal bearings	134
	Advantages of hollow shafts	134
	Effects of too large propellers on the life of shafts	135
	Cast steel shafts	135
	Forged scrap steel shafts	135
	Evil effect of the gun-metal coverings of shafts	135
Shock, W. H., U.S. Navy	Progress of marine engineering during the last fifty years...	56
Sigaudy, P.	*Water-tube Boilers in high-speed Ocean Steamers* ...	58
	Reply to the discussion on the above paper	65
	The durability of water-tube boilers	65
	The suitability of small-tube water-tube boilers for long-distance steaming	65
Swan, H. F.	Steam railway ferries made for the River Volga by his firm...	112
	Advantages of twin screws in ice-breaking steamers	112
	Probable future of ice-breaking steamers...	113
Taylor, D. W., U.S. Navy ...	Experience with non-flammable wood in the U.S. Navy ...	30
	The influence of cavitation on the efficiency of screw propellers	143
	Professor Hele-Shaw's experiments on the nature of surface resistance...	154
Thompson, Robert ...	Question as to length of time required to prepare non-flammable wood	33
	Mr. Johnson's method of approximately calculating hull weights	118
Thornycroft, J. I., F.R.S. ...	The possibility of using small-tube water-tube boilers in long-distance steaming	63
	The development of marine boilers	64
	Effect of partly immersed propellers on the life of shafts ...	133
	Advantage of tapering the liners on shafts	133
	Effect of vibration on the life of shafts	133
	The cavitation caused by screw propellers at high speed ...	143

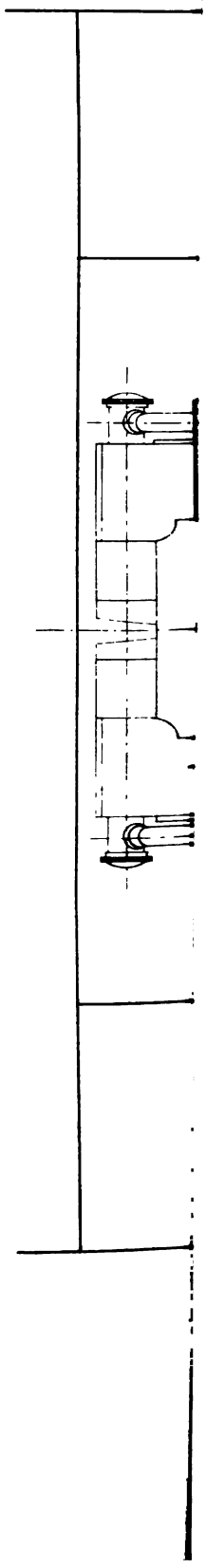
Name of Writer or Speaker.	*Title of Paper*, or Subject under Discussion.	Page.
Tuxen, Captain J. C., R.D.N.	*Danish Steam Railway Ferries and Ice-breaking Steamers* ...	105
	Reply to the discussion on his paper	115
Woodward, J. J., U.S. Navy	Experience with non-flammable wood in the U.S. Navy ...	30
	Strength of Oregon pine when rendered non-flammable ...	31
	Conductivity of non-flammable wood	31
	Difficulty of painting non-flammable wood	31
Wales, H.R.H., The Prince of, K.G., &c.	Address of welcome to the Congress	li
White, Sir William, K.C.B., LL.D., Sc.D., F.R.S.	Experiments on armour	23
	Resistance of cracked armour-plates	24
(*See also Chairman*)	Recent improvement in the manufacture of armour ...	24
	The possibility of using small-tube water-tube boilers in long-distance steaming	62
	Proposed boiler installation in new French cruisers ...	6
	The contributions to the mathematical theory of Naval Architecture made in the last century	101
	The services of the Institution in diffusing technical knowledge	101
	The law of comparison of the performance of a ship and her model, originally due to M. Reech	101
	The debt owed by Naval Architects to mathematicians ...	102
	Naval Architecture not an exact science	102
	International character of the advances made in the theory of Naval Architecture	102
	His own co-operation with the late Mr. William John ...	102
	Professor Hele-Shaw's experiments on the nature of surface resistance	154
Wingfield, C. Humphrey ...	The cavitation caused by screw propellers at high speed ...	144
	Mr. Parson's experiments on cavitation	144
	Tensile strength of water	144
Yendo, Captain K., Imperial Japanese Navy	Value of non-flammable wood in warship building	30

UNWIN BROTHERS, PRINTERS, LONDON AND WOKING.

peed Ocean Steamers.



UNIV. OF MICH.



UNIV. OF MICH.

To Illustrate Monsieur E. Bertin's Paper: Hardened Armour Plates and broken Projectiles.

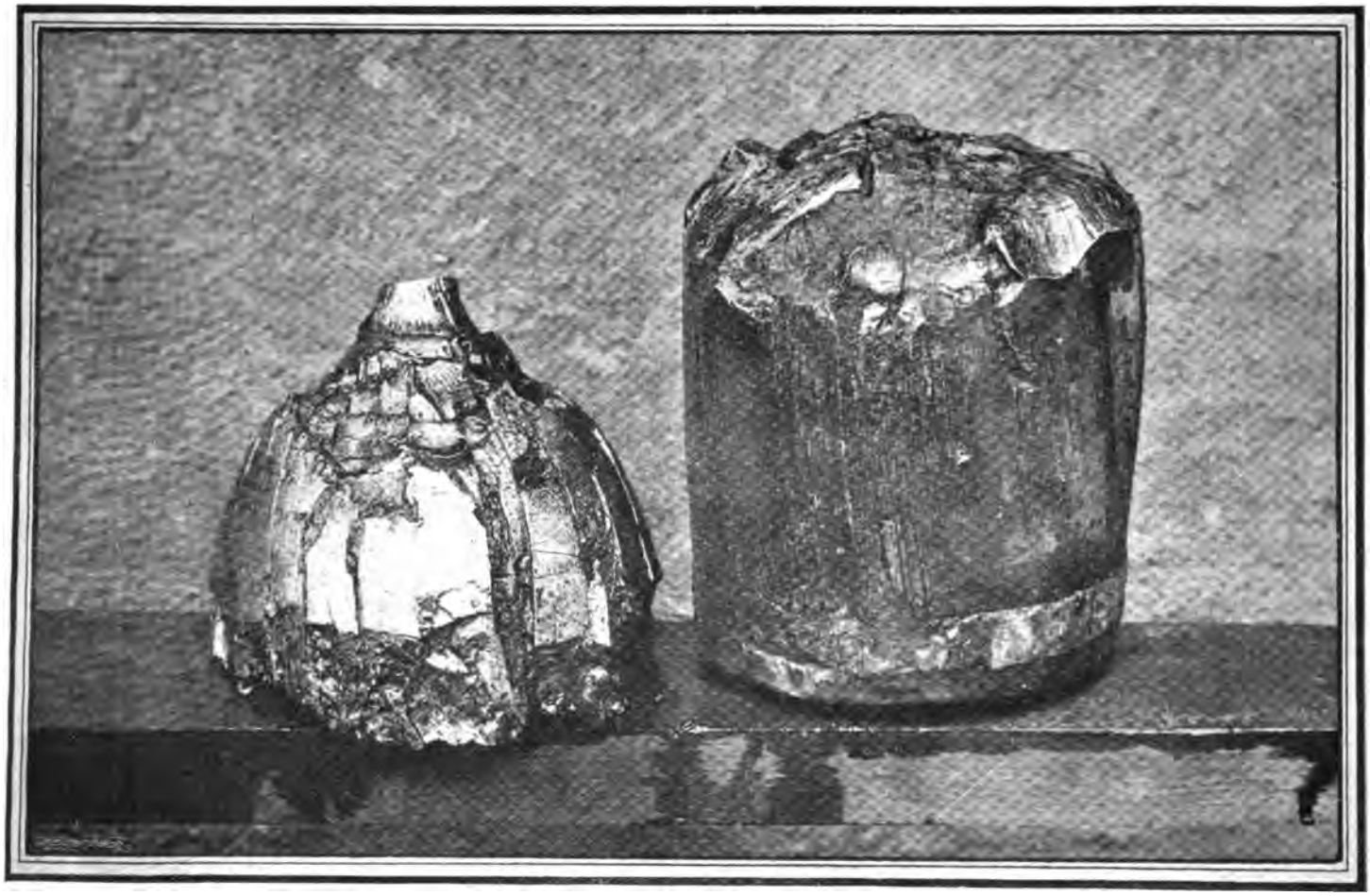


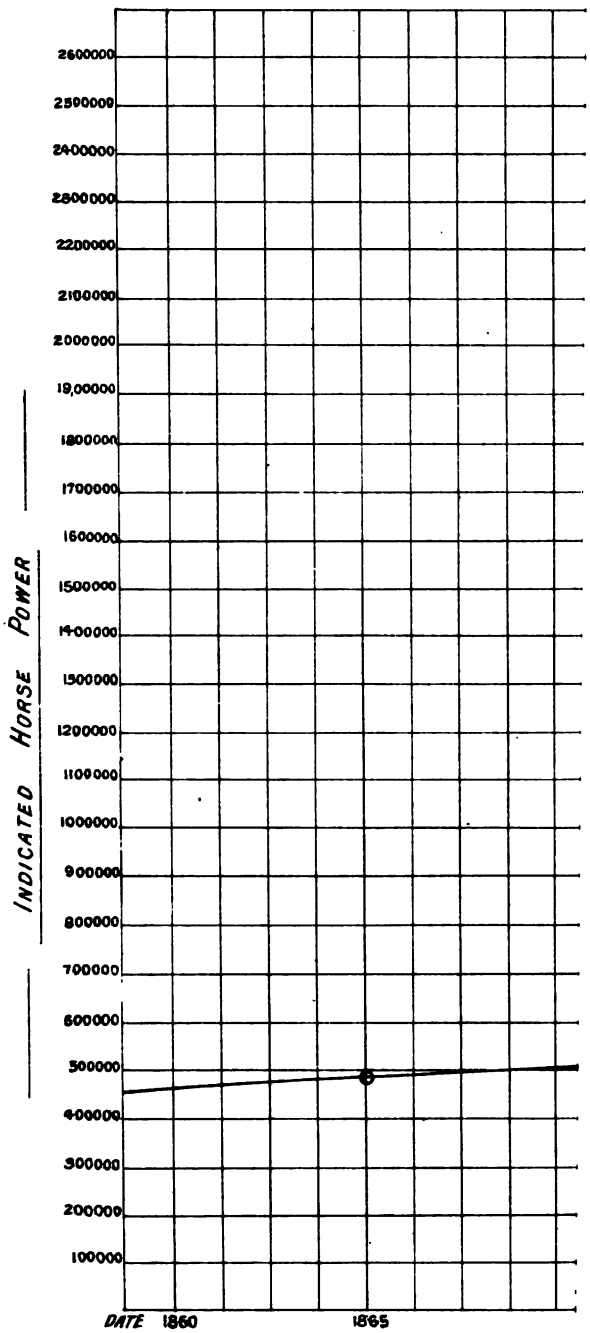
FIG. 4.

FIG. 5.

To Illustrate Sir
and Progress of J
Foundi

SHEWING THE
R

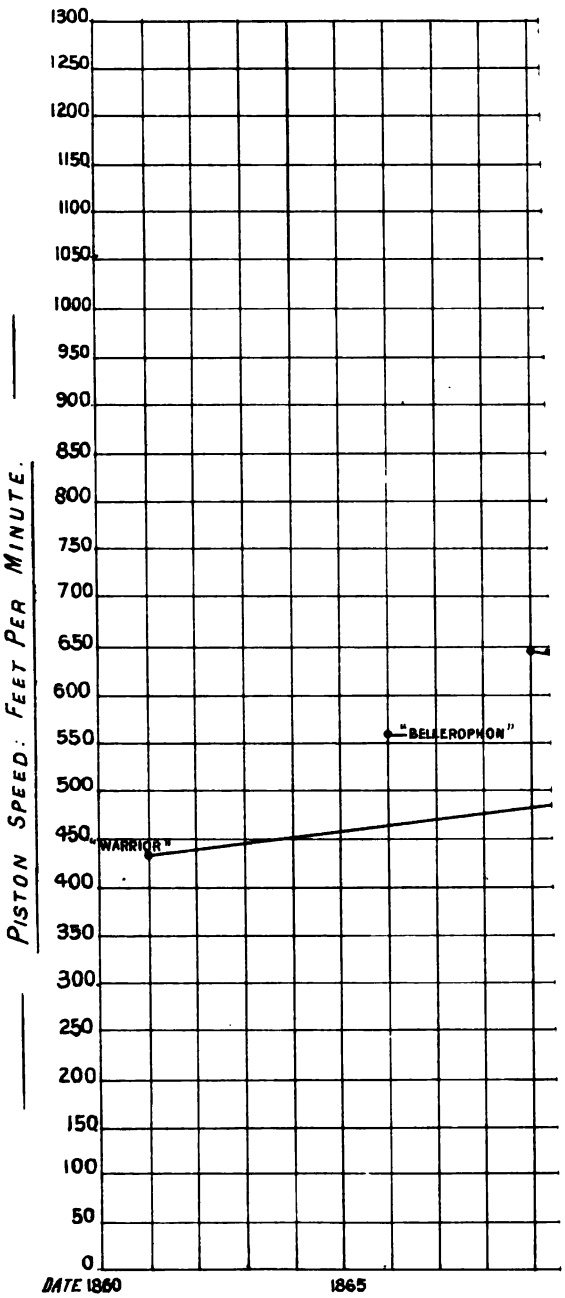
THE DOTTED CURVE



UNIV. OF MICH.

To Illustra
and Progre

SHEWI



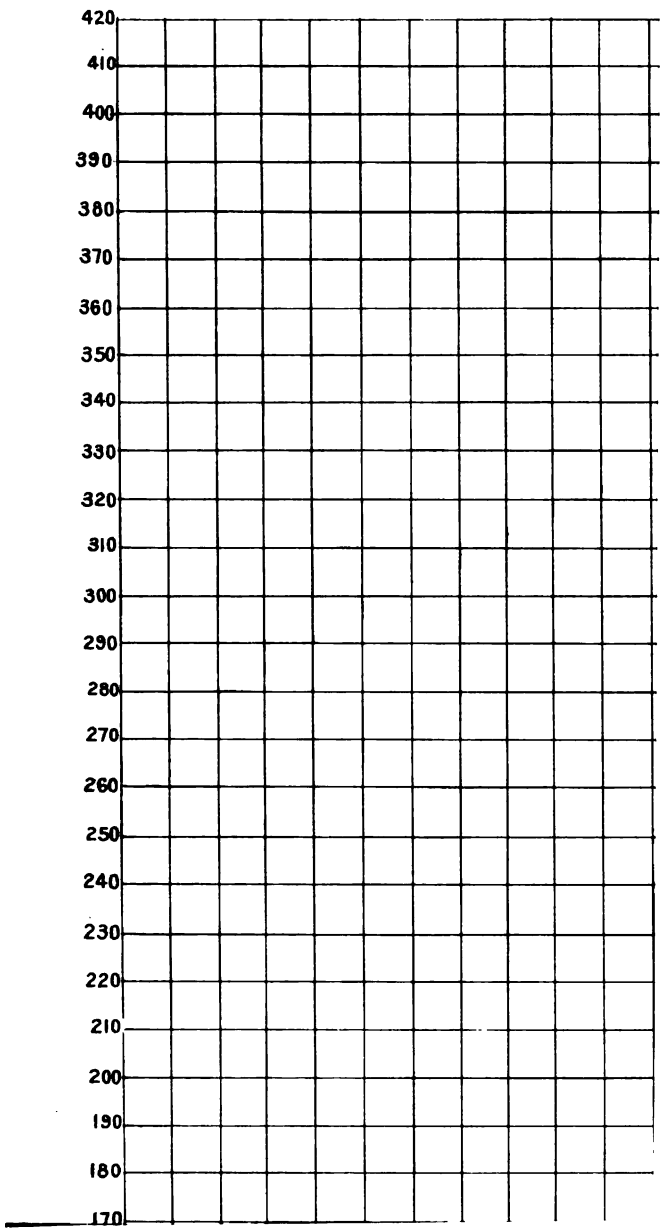
V.
OF
MICH.

NOTE;-

Trans. Inst. Naval Architects, Vol. XXXIX., 18

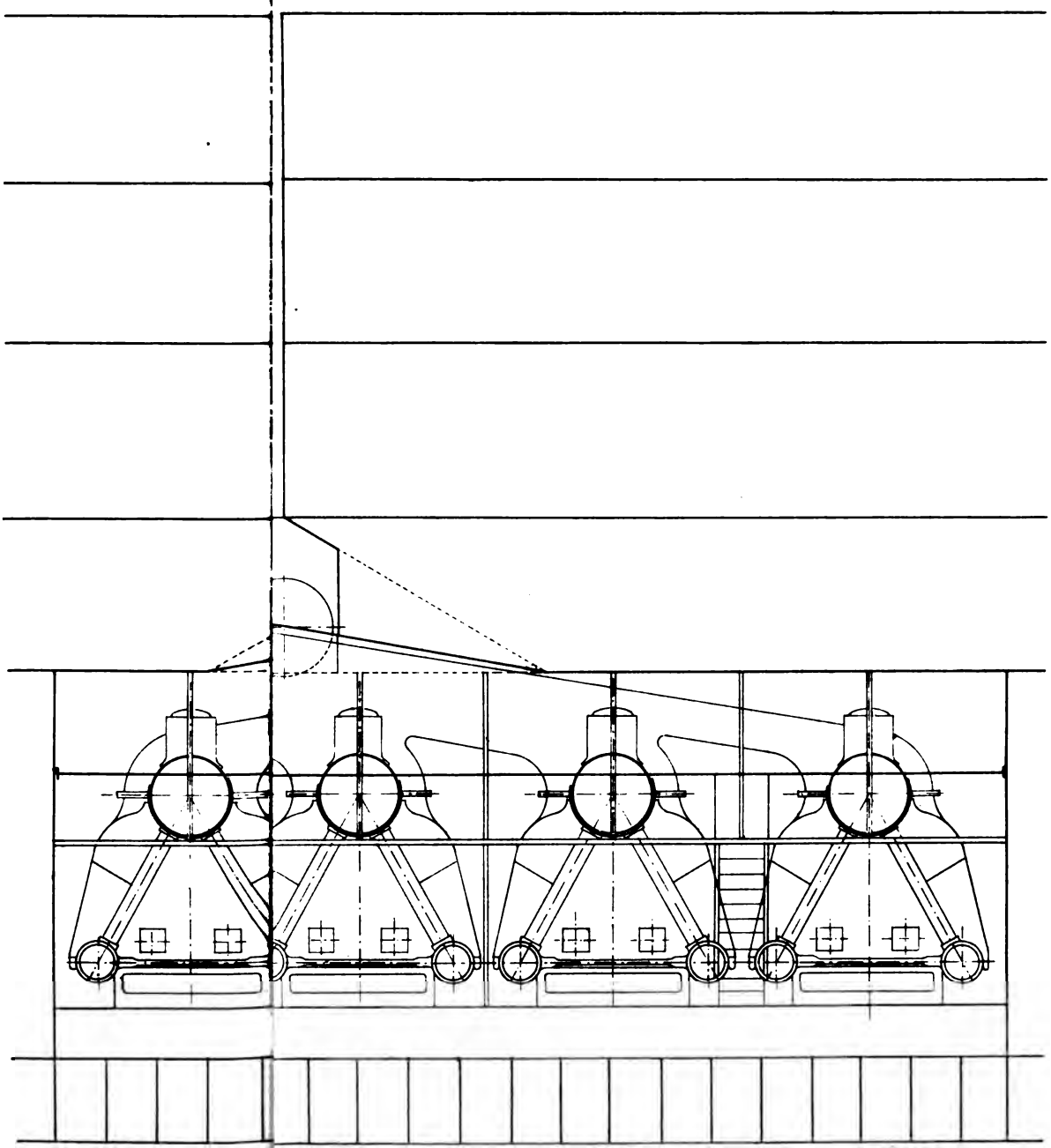
To Illustrate Sir J
and Progress of M
Founda

SHOWING

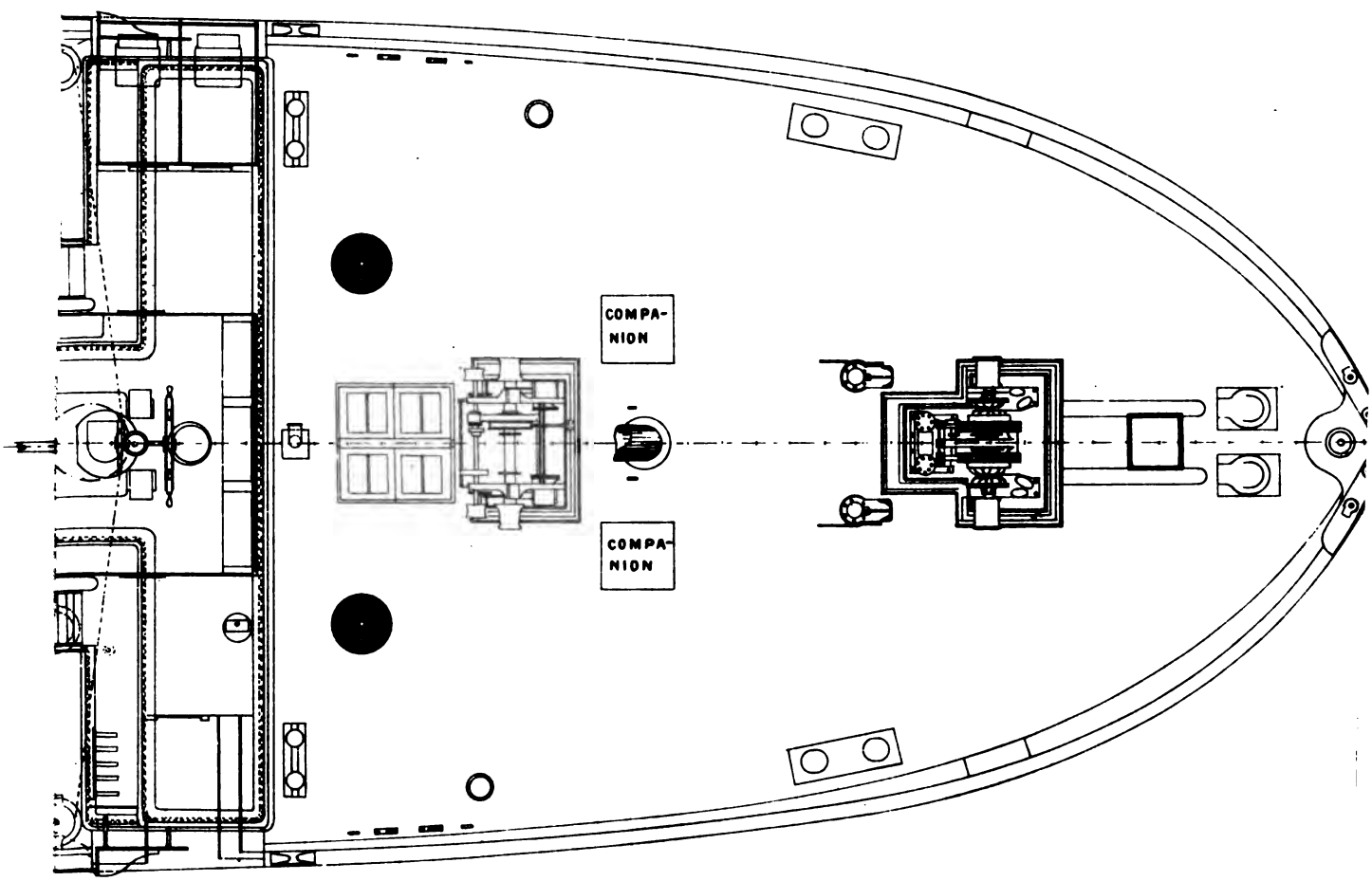


UNIV. OF MICH.

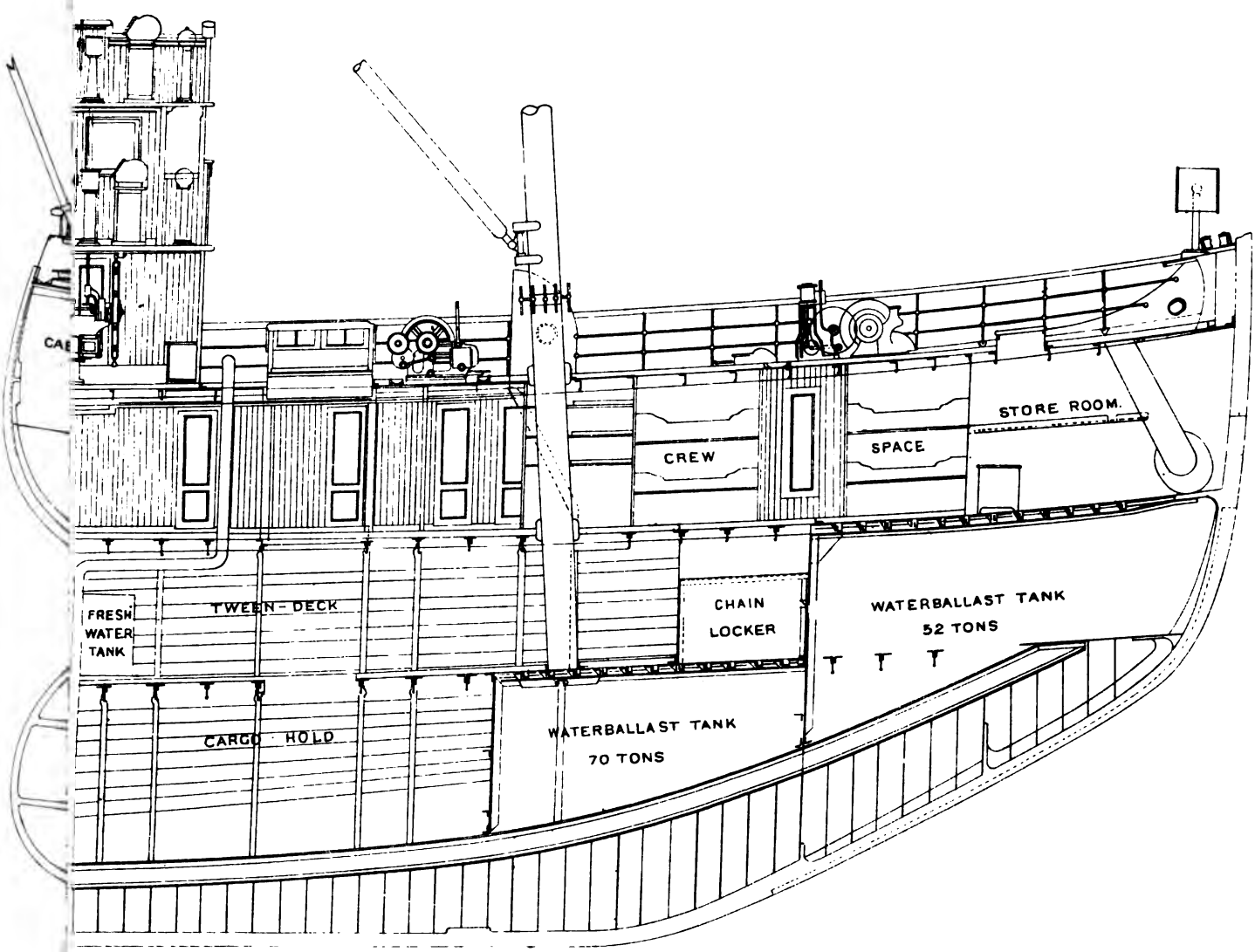
speed Ocean Steamers.



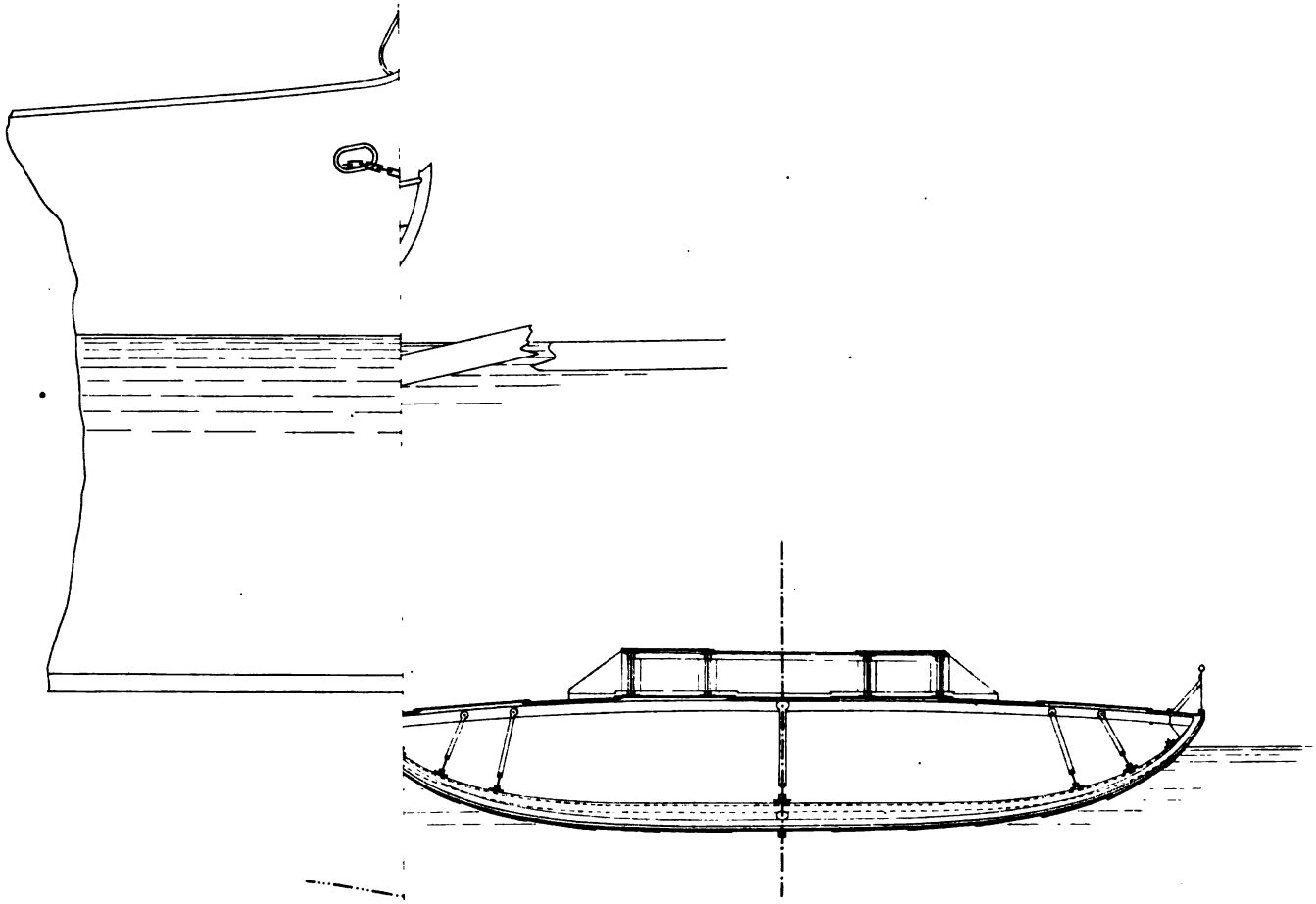
UNIV. OF MICH.


COMPA-
NION
COMPA-
NION

FR
WA
TA


CREW
STORE ROOM.
SPACE
FRESH WATER TANK
TWEEN-DECK
CHAIN LOCKER
WATERBALLAST TANK 52 TONS
CARGO HOLD
WATERBALLAST TANK 70 TONS

UNIV. OF MICH.



Dimensions

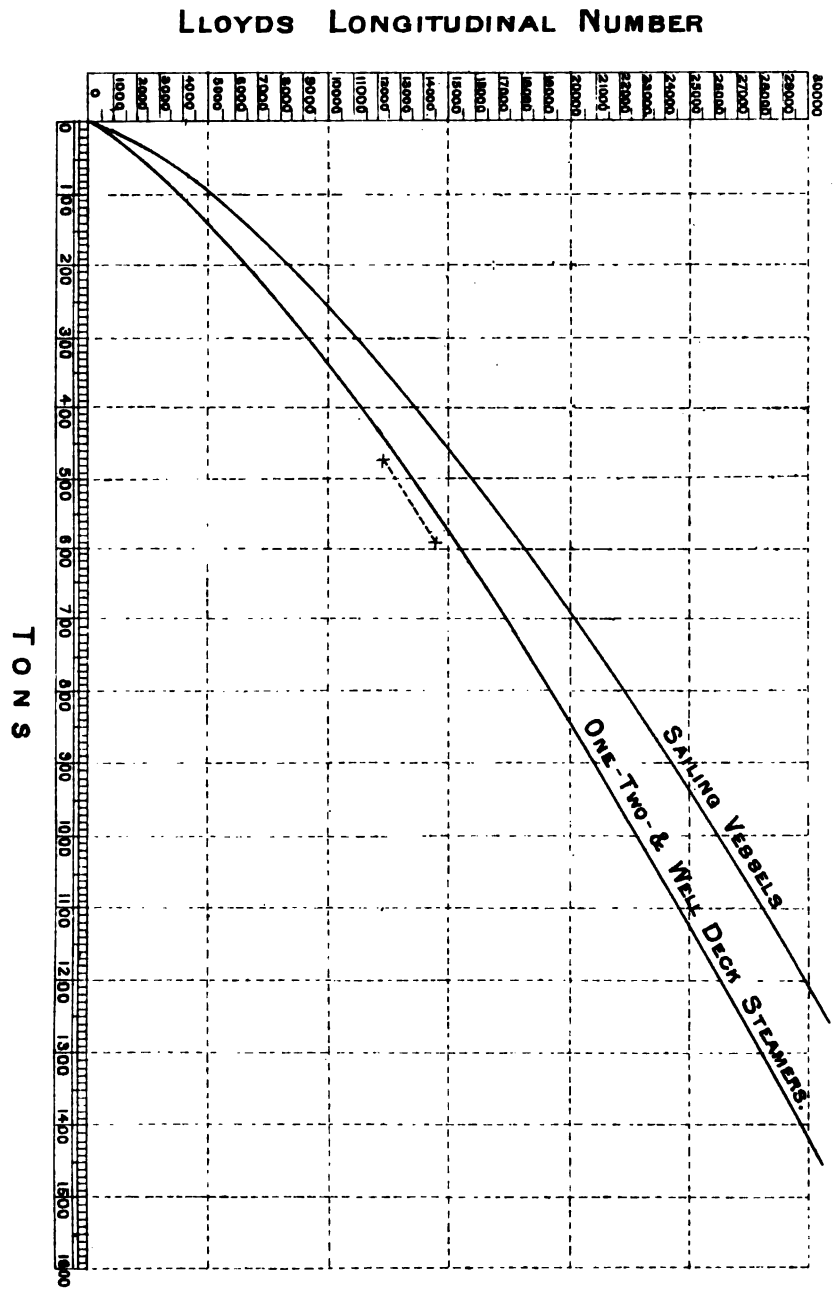
LENGTH OVERALL	54' 4"
BREADTH EXTREME	36' 0"
DEPTH OF HOLD	4' 8"

Scale : 1/8" = 1 Ft.

UNIV. OF MICH.

Trans. Inst. Naval Architects, Vol. XXXIX., 1898.

To Illustrate Mr. J. Johnson's Paper



UNIV. OF MICH.

Fig 1

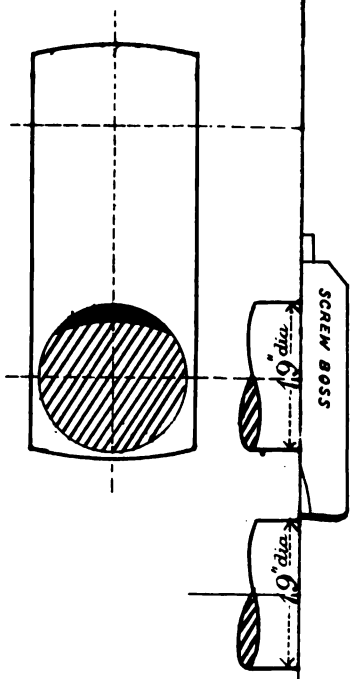


Fig. 7 CRANK SHAFT

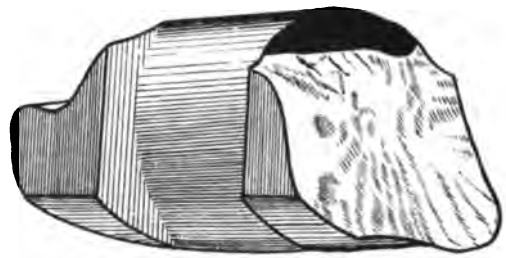


Fig. 8 TUNNEL SHAFT

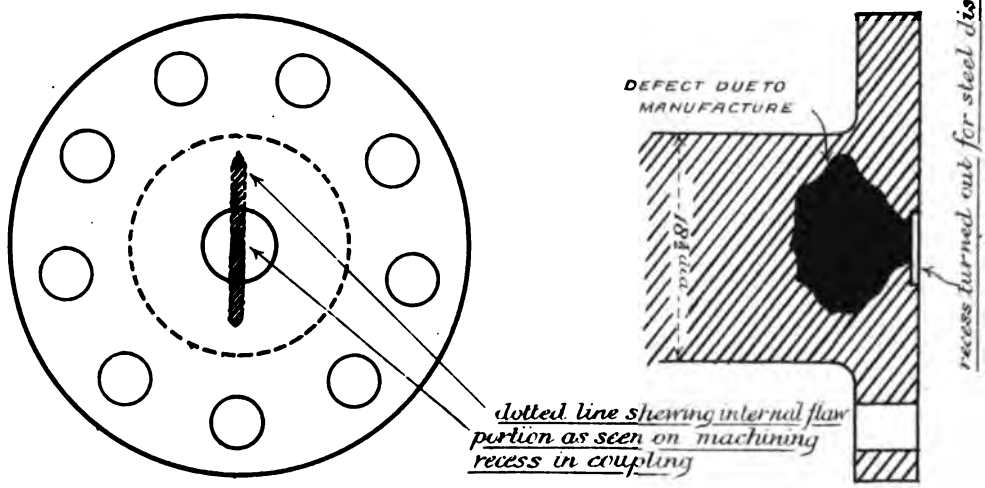
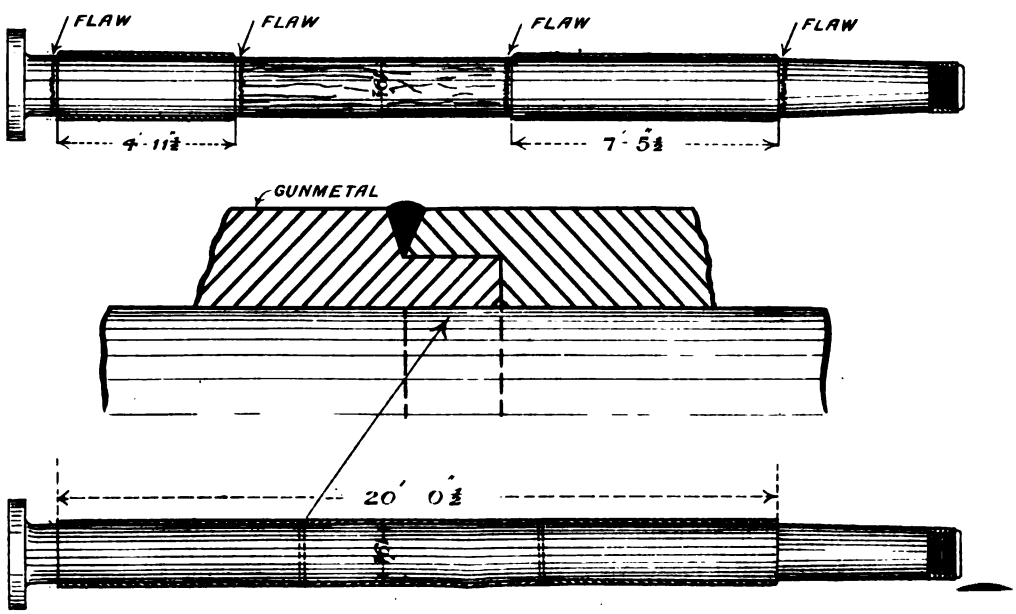
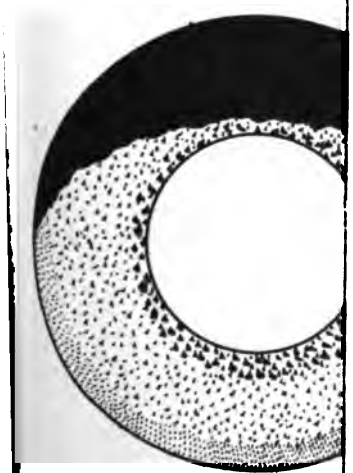
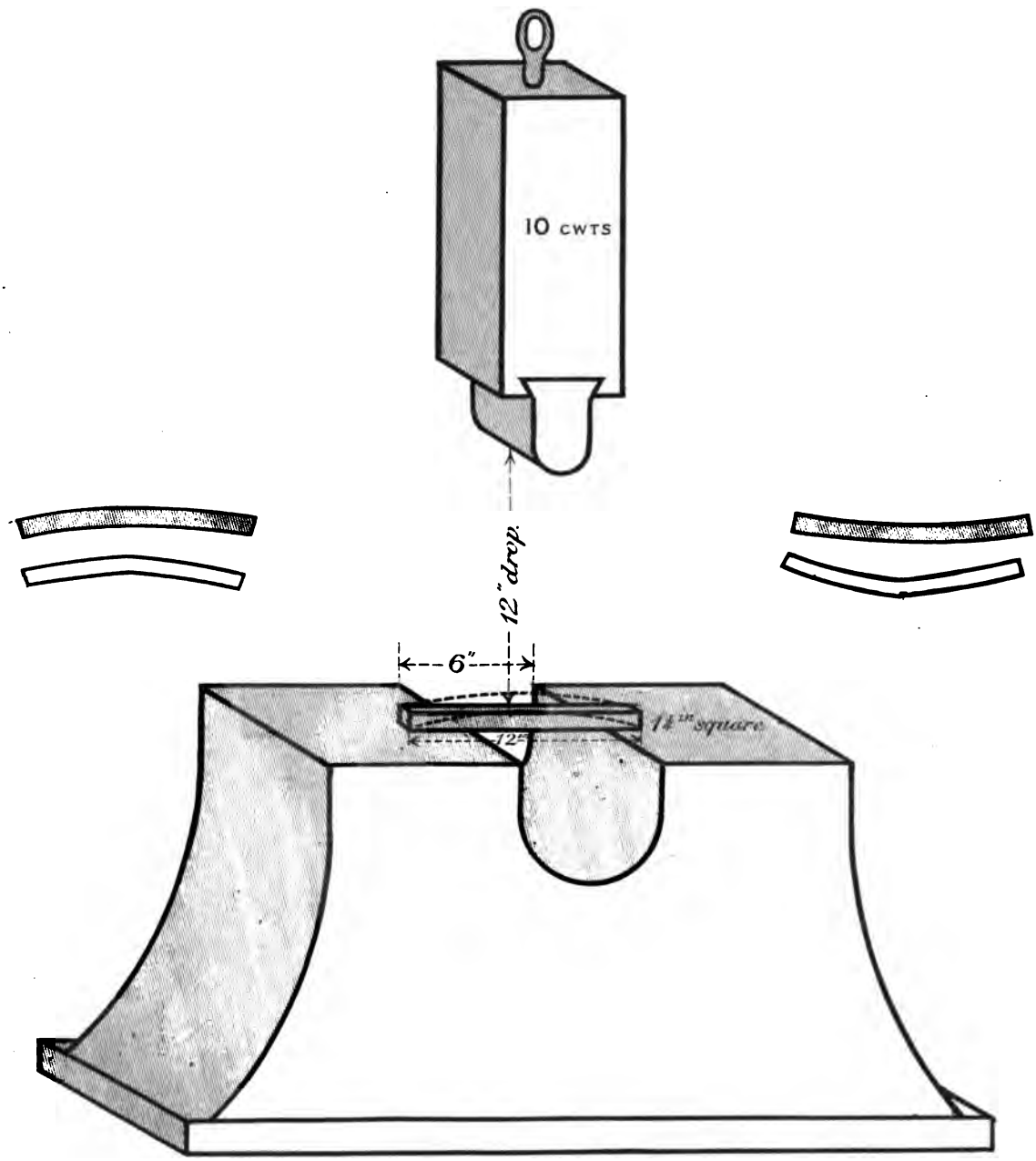

DEFECT DUE TO MANUFACTURE
18" dia.
recess turned out for steel disc
dotted line shewing internal flaw portion as seen on machining recess in coupling

Fig. 9





To Illustrate Mr. G. W. Manuel's Paper: Crank and other Shafts used in the Mercantile Marine.



UNIV. OF

To Illustrate Professor H. S. Hele-Shaw's Paper: Experimental Investigation of the Nature of Surface Resistance on Ships and in Pipes.

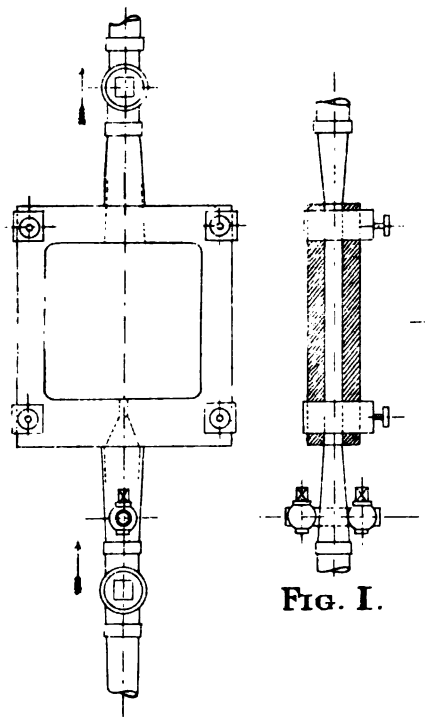


FIG. 1.

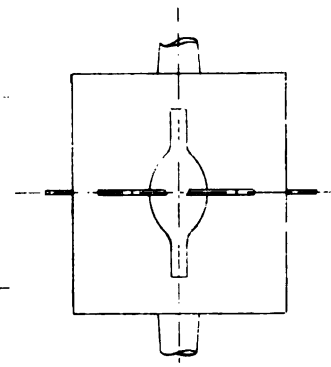


FIG. 2.

FIG. 3.

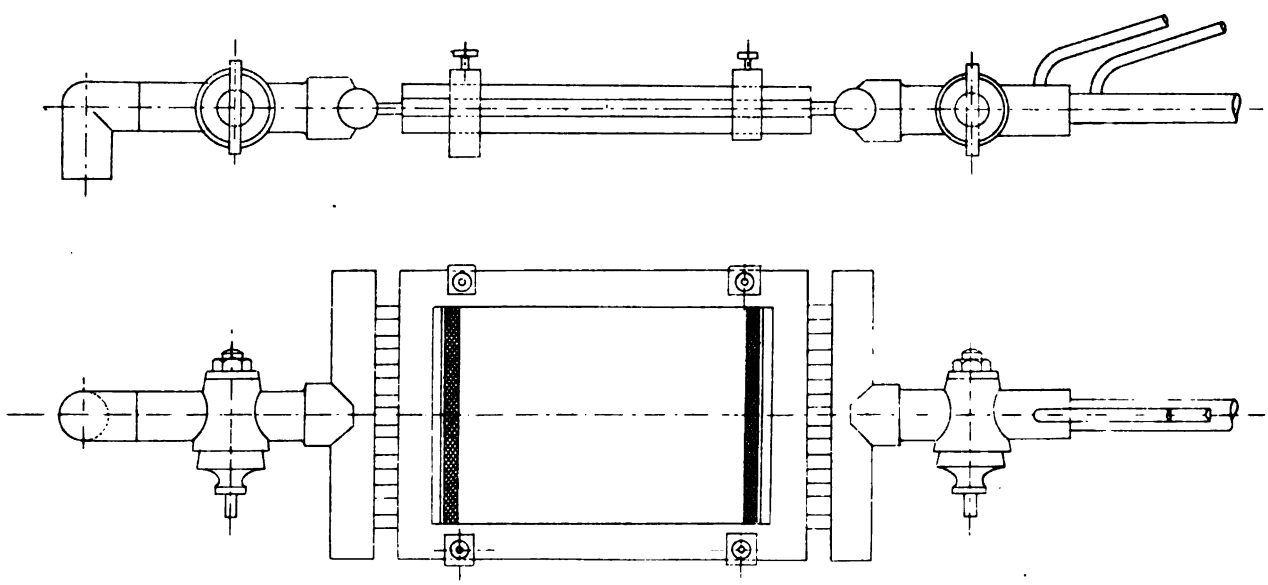


FIG. 4.

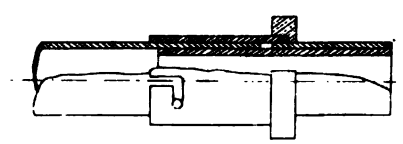


FIG. 5.

UNIV. OF

To Illustrate Professor H. S. Hele-Shaw's Paper: Experimental Investigation of the Nature of Surface Resistance on Ships and in Pipes.

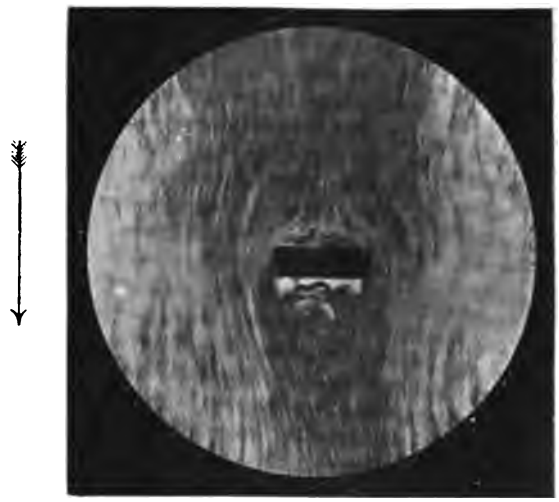


Fig. 6.

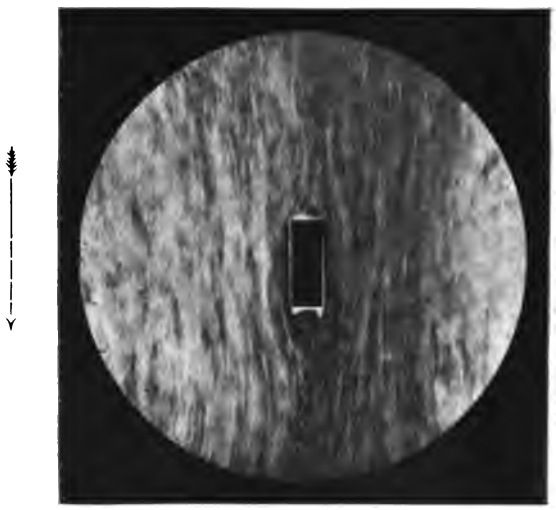


Fig. 7.

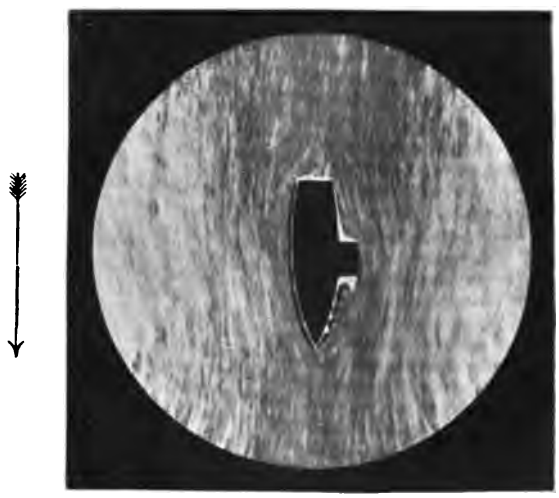


Fig. 8.

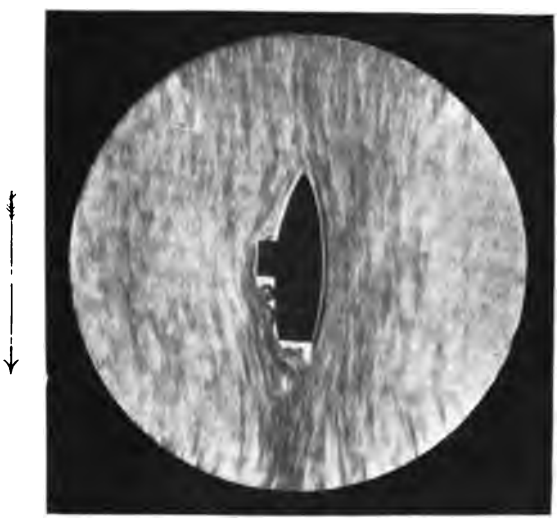


Fig. 9.

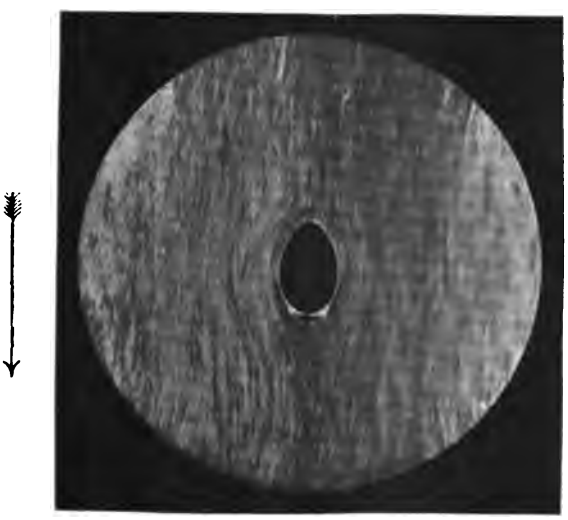


Fig. 10.

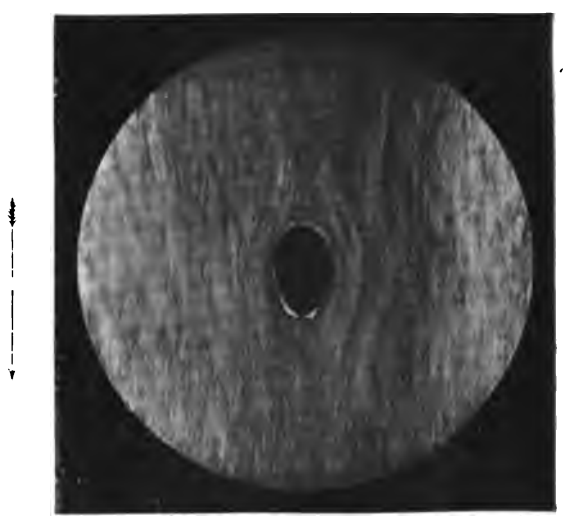


Fig. 11.

UNIV. OF MICH

To Illustrate Professor H. S. Hele-Shaw's Paper: Experimental Investigation of the Nature of Surface Resistance on Ships and in Pipes.

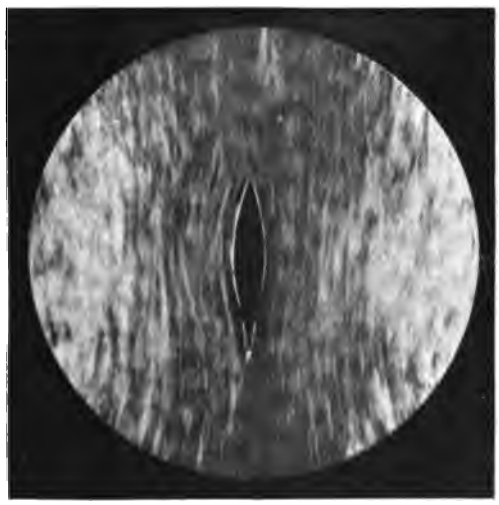


Fig. 12.

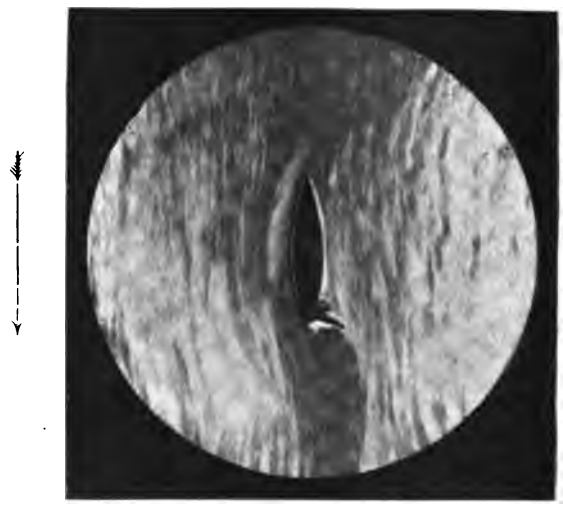


Fig. 13.

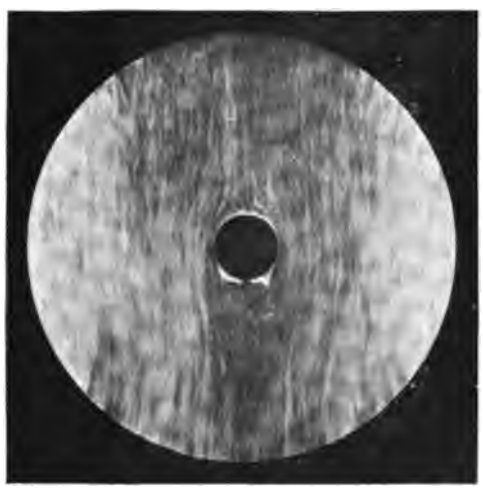


Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

To Illustrate Professor H. S. Hele-Shaw's Paper: Experimental Investigation of the Nature of Surface Resistance on Ships and in Pipes.

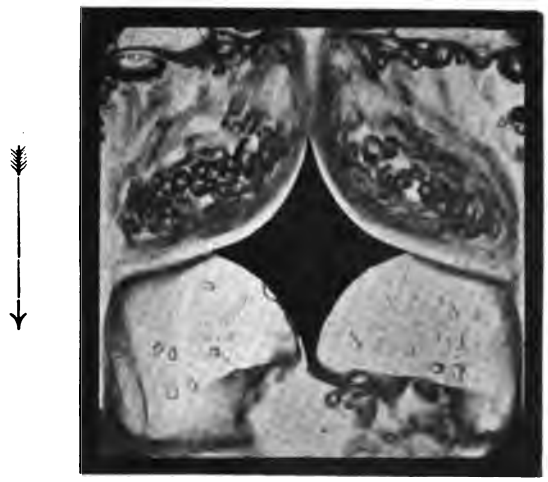


Fig. 18.

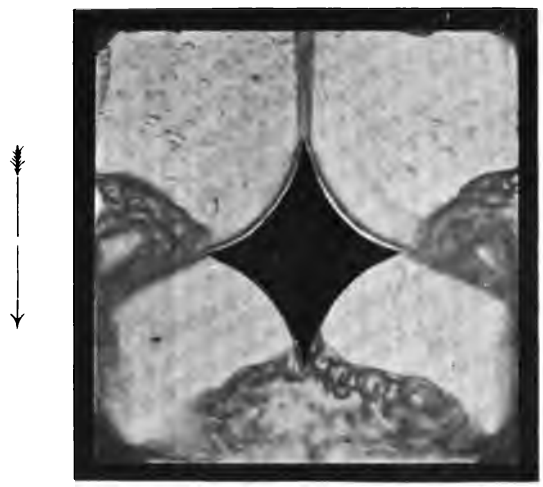


Fig. 19.

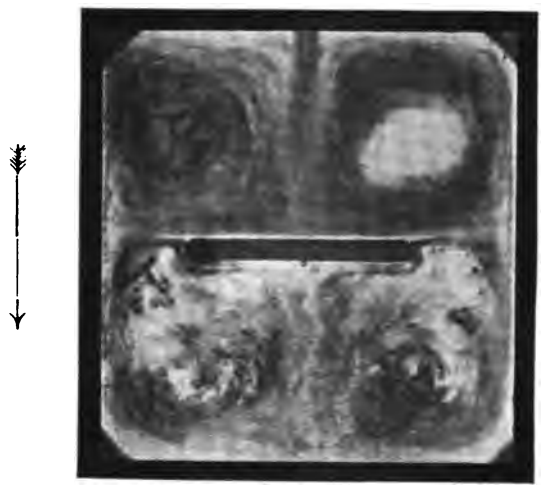


Fig. 20.

Fig. 21.

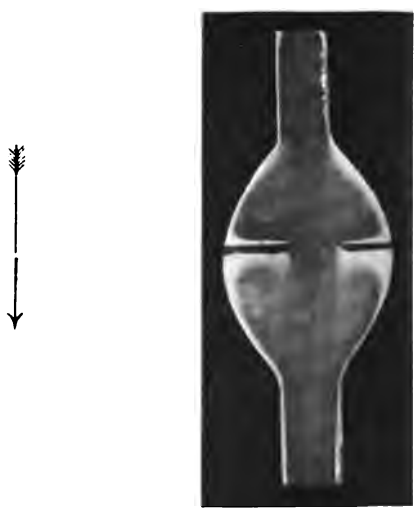


Fig. 22.

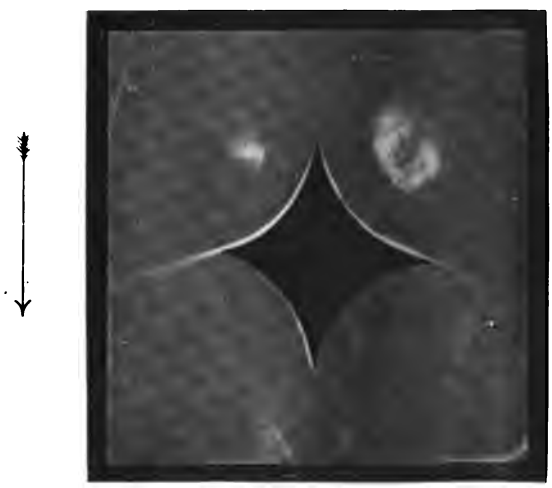


Fig. 23.

UNIV. OF MIC